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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent Application of:
Kei YAMAMOTO et al.

Application No.: 10/608,776

Confirmation No.: 8129

Filed: June 30, 2003

Art Unit: 2828

For: SEMICONDUCTOR LASER DEVICE AND OPTICAL DISK UNIT USING THE SAME

Examiner: Delma R. Flores Ruiz

SUBMISSION OF VERIFIED TRANSLATION OF FOREIGN PRIORITY DOCUMENT

MS Amendment
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Dear Sir:

INTRODUCTORY COMMENTS

This application claims priority under 35 USC 119 to Japanese patent application no. 2002-209795, filed July 18, 2002. Pursuant to 35 USC 119, a certified copy of said patent application was submitted on June 30, 2003, thereby perfecting the priority claim.

In support of the Applicants' claim for priority, filed herewith is a verified translation of the above-identified priority document.

It is respectfully requested that the receipt of the document attached hereto be acknowledged in this application.

In the event the U.S. Patent and Trademark office determines that an extension and/or other relief is required, applicants petition for any required relief including extensions of time and authorize the Commissioner to charge the cost of such petitions and/or other fees due in connection with the filing of this document to Deposit Account No. 03-1952 referencing docket no. 204552028900.

Dated: August 17, 2005

Respectfully submitted,

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VERIFICATION OF ENGLISH TRANSLATION

Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450

Dear Sir:

I, Hiroshi Yamazaki, of c/o IMP Building, 1-3-7, Shiromi, Chuo-ku, Osaka 540-0001 Japan, declare that I am conversant in both the Japanese and English languages and that the English translation as attached hereto is accurate translation of Japanese Patent Application No. 2002-209795 filed July 18, 2002.

Signed this 5th day of August, 2005

Hiroshi Yamazaki

Hiroshi YAMAZAKI

PATENT OFFICE

JAPANESE GOVERNMENT

This is to certify that the annexed is a true copy of the following application as filed with this Office.

Date of Application: July 18, 2002

Application Number: Patent Application No. 2002-209795

Applicant: SHARP KABUSHIKI KAISHA

Commissioner,

Patent Office

(Seal)

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Addressee:	Commissioner, Patent Office
International Patent Classification:	H01S 3/18
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Item:	Specification	1 copy
Item:	Drawings	1 copy
Item:	Abstract	1 copy
Registration No. of General Power:	0208766	

Request for Proof Transmission: Yes

Document name: Specification

Title of the invention: SEMICONDUCTOR LASER DEVICE AND OPTICAL DISK UNIT USING THE SAME

What is claimed is:

1. A semiconductor laser device having an oscillation wavelength of larger than 760 nm and smaller than 800 nm in which at least a lower clad layer, a lower guide layer, an active region, an upper guide layer and an upper clad layer are supported by a GaAs substrate, the active region having a quantum well structure in which one or more well layers and barrier layers are stacked, wherein

said one or more well layers and said barrier layers are formed of any one of InGaP, InGaAsP and GaAsP, and

said guide layers are formed of $Al_xGa_{1-x}As$ ($0.20<x\leq1$).

2. The semiconductor laser device according to Claim 1, wherein

a value of x representing a mole fraction of Al in the group-III elements of said guide layers is larger than 0.25.

3. The semiconductor laser device according to Claim 1 or 2, wherein

said upper and lower clad layers contain Al, and

a value of x is smaller than a value of an Al mole fraction of said upper and lower clad layers.

4. The semiconductor laser device according to Claim 3, wherein

the value of x varies stepwise or continuously and in such a fashion as to increase with increasing nearness to said upper and lower clad layers.

5. The semiconductor laser device according to any one of Claims 1 to 4, wherein

a value of x of at least a portion in contact with a barrier layer of said guide layer is smaller than 0.4.

6. The semiconductor laser device according to any one of Claims 1 to 5, wherein

said one or more well layers have a compressive strain.

7. The semiconductor laser device according to any one of Claims 1 to 6, wherein

said barrier layers have a tensile strain.

8. An optical disk unit in which the semiconductor laser device as defined in any one of Claims 1 to 7 is used as a light-emitting device.

Detailed explanation of the invention:

[0001]

Technical field to which the invention pertains:

The present invention relates to a semiconductor laser device which contains no Al in its active region and whose oscillation wavelength is in a 780 nm band (i.e., larger than 760 nm and smaller than 800 nm). The invention also relates to an optical disk unit using the semiconductor laser device.

[0002]

Prior art:

Semiconductor laser devices of the 780 nm band have been widely used as semiconductor laser devices for reproducing discs such as CDs (Compact Disks) and MDs (Mini Disks). Among others, a semiconductor laser device which exhibits high reliability even with 120 mW or higher power is keenly desired as a semiconductor laser device for use with CD-Rs (CD-Recordable's) capable of high-speed writing.

[0003]

In the case of a conventional AlGaAs quantum well structure in which Al is contained in well layers and barrier layers, there is an issue that the reliability particularly at high temperatures or high power deteriorates. The reason of this is considered that Al, being an active substance, would react even with a trace quantity of impurities such as oxygen, thereby amplifying the deterioration of the material. A countermeasure for this could be that high power and high reliability are

implemented by providing a structure in which Al is not contained in the well layer/barrier layer. However, actually, there has not yet been developed a semiconductor laser device that has enough reliability with 120 mW or higher power at the 780 nm band.

[0004]

As semiconductor laser devices of an oscillation wavelength of 810 nm with a structure in which Al is not contained in the well layer/barrier layer, there have been proposed those disclosed in Japanese Patent Laid-Open Publication HEI 11-220244 and Japanese Journal of Applied Physics Vol. 38 (1999) pp. L387 - L389. Based on this prior art, we made a semiconductor laser device which would oscillate at 780 nm.

[0005]

Fig. 12 is a structural view showing a semiconductor laser device of an InGaAsP-based quantum well structure in which no Al is contained in the well layers nor in barrier layers. Fig. 13 is a diagram of energy band gap (Eg) in the vicinity of the active region in the semiconductor laser device shown in Fig. 12.

[0006]

Fig. 12 shows an n-type GaAs substrate 1, an n-type $Al_{0.63}Ga_{0.37}As$ lower clad layer 2, an $In_{0.484}Ga_{0.516}P$ lower guide layer 3, and an active region 4. In this case,

the active region 4 has a double quantum well (DQW) structure composed of barrier layers 5 and well layers 6. There are also shown an $In_{0.484}Ga_{0.516}P$ upper guide layer 7, a p-type $Al_{0.63}Ga_{0.37}As$ upper clad layer 8, a p-type GaAs protective layer 9, a SiO_2 current blocking layer 10, an n-side electrode 11, and a p-side electrode 12. The barrier layer 5 is formed of $In_{0.4}Ga_{0.6}P$, in which the strain is -0.62% in tensile strain and the layer thickness is 8 nm for each of the layers 5a and 5c and 7 nm for the layer 5b. It is noted that Eg of $In_{0.4}Ga_{0.6}P$ can be calculated as about 2.02 eV without consideration of strain, but it would be about 1.93 eV - 1.96 eV due to influences of tensile strain. The well layers 6 are formed of $In_{0.162}Ga_{0.838}As_{0.671}P_{0.329}$, in which Eg is 1.57 eV, there holds a lattice matching with the substrate, and the layer thickness is 5 nm for each of the layers 6a and 6b. Also, the AlGaAs upper clad layer 8 has a ridge stripe structure with the stripe width being 2.5 µm.

[0007]

In the conventional semiconductor laser device in which no Al is contained in the well layers nor in the barrier layers, an $In_{0.4}Ga_{0.6}P$ barrier layer is inserted between an $In_{0.484}Ga_{0.516}P$ guide layer (Eg = 1.89 eV) and an InGaAsP well layer so that a difference in Eg, "ΔEg," from layers adjacent to the well layers (i.e., barrier

layers 5) becomes 0.36 eV to 0.39 eV, which is larger than that of semiconductor laser devices in which Al is contained in the well layers and the barrier layers. For example, in the quantum well structure of AlGaAs-based semiconductor lasers, normally, ΔEg = approx. 0.25 eV. Thus, in semiconductor laser devices in which no Al is contained in the well layers nor in the barrier layers, a material that allows the largest possible ΔEg to be obtained is selected as the Al-free material for the barrier layer 5 in order to fulfill secure confinement of carriers.

[0008]

Problem to be solved by the invention:

However, the conventional semiconductor laser device of the InGaAsP-based quantum well structure containing no Al in the well layers nor in the barrier layer has the following problems. That is, measuring the characteristics of the semiconductor laser device showed as high a threshold current as 100 mA, which means that good characteristics are not obtained. Its temperature characteristic is also so poor that the semiconductor laser device does not oscillate at 80°C or higher. In the case of an AlGaAs-based semiconductor laser device of the 780 nm band in which Al is contained in the well layers and the barrier layers, the threshold current is 35 mA and the

temperature characteristic is about 110K. As is obvious, as compared with the AlGaAs-based semiconductor laser device, the InGaAsP-based semiconductor laser device is deteriorated in characteristics, conversely.

[0009]

Accordingly, an object of the present invention is to provide an Al-free semiconductor laser device capable of remarkably improving the characteristics regardless of the level of ΔEg, as well as an optical disk unit using the semiconductor laser device.

[0010]

Means of solving the problem:

In order to achieve the above object, according to a first invention, there is provided a semiconductor laser device having an oscillation wavelength of larger than 760 nm and smaller than 800 nm in which at least a lower clad layer, a lower guide layer, an active region, an upper guide layer and an upper clad layer are supported by a GaAs substrate, the active region having a quantum well structure in which one or more well layers and barrier layers are stacked, wherein the one or more well layers and the barrier layers are formed of any one of InGaP, InGaAsP and GaAsP, and the guide layers are formed of $Al_xGa_{1-x}As$ $(0.20<x\leq1)$.

[0011]

As will be detailed later, with InGaAsP varied in mole fractions, the values of conduction-band energy (Ec) and valence-band energy (Ev) vary even if Eg remains unchanged. In particular, in the case of InGaAsP having such mole fractions that its lattice constant is close to that of the GaAs substrate, Eg extends toward the valence-band side. Due to this, with an InGaAsP-based material used for the well layer and the barrier layer, even if ΔEg between those layers is set to a larger value, the Ev difference (|ΔEv|) alone would become larger, while a value of Ec difference (|ΔEc|) comparable to that of AlGaAs-based semiconductor laser device cannot be ensured.

[0012]

Accordingly, in the case of a conventional semiconductor laser device of the 780 nm band using InGaP for the barrier layers and the guide layers, there would occur overflow of electrons due to a small |ΔEc|, which would cause poor characteristics such as increase in threshold current or deterioration of temperature characteristic.

[0013]

With the above-described constitution of the present invention, an AlGaAs guide layer having a mole fraction of Al in the group-III elements that is larger than 0.20 is provided outside the corresponding barrier

layer containing no Al and formed of any one of InGaP, InGaAsP and GaAsP. Therefore, |ΔEc| between the well layer, which contains no Al and formed of any one of InGaP, InGaAsP and GaAsP, and the guide layer, is set to about 0.12 eV or larger. This value of about 0.12 eV corresponds to a value of ΔEc between the barrier layer and the well layer resulting when AlGaAs having a group-III Al mole fraction of about 0.27 is used as the barrier layer in the quantum well structure of an AlGaAs-based semiconductor laser. Therefore, the overflow of electrons is suppressed equally or more than in an AlGaAs-based semiconductor laser.

[0014]

As a result of this, the overflow of electrons from the well layer, which has been a cause of poor characteristics in the semiconductor laser device using the InGaP guide layer, can be solved, so that the characteristics of the semiconductor laser device of the 780 nm band containing no Al in the active region are improved remarkably. Furthermore, by virtue of the presence of the barrier layer containing no Al, the well layer is never neighbored in contact by the AlGaAs guide layer containing Al. Thus, high reliability is ensured.

[0015]

In one embodiment of the semiconductor laser device of the first invention, a value of x representing a

mole fraction of Al in the group-III elements of the guide layer is larger than 0.25.

[0016]

In this embodiment, $|\Delta Ec|$ between the AlGaAs guide layer and the well layer is securely made larger than 0.12 eV. Thus, the overflow of electrons from the well layer(s) can be suppressed reliably.

[0017]

In one embodiment of the semiconductor laser device of the first invention, the upper and lower clad layers contain Al, and a value of x is smaller than a value of an Al mole fraction of the upper and lower clad layers.

[0018]

In this embodiment, $|\Delta Ec0|$ of the AlGaAs guide layer, and $|\Delta Ev0|$, which is an Ev difference of the AlGaAs guide layer from the GaAs substrate, become smaller than those of the lower clad layer and the upper clad layer. Therefore, the overflow of electrons is suppressed in the guide layer(s), so that the temperature characteristic can be improved.

[0019]

In one embodiment of the semiconductor laser device of the first invention, the value of x varies stepwise or continuously and in such a fashion as to increase with increasing nearness to the upper and lower

clad layers.

[0020]

In this embodiment, $|\Delta Ec0|$ and $|\Delta Ev0|$ of the AlGaAs guide layer(s) increase more and more from the well layer side toward the lower clad layer and upper clad layer side. Therefore, the overflow of electrons is suppressed more reliably in the guide layers.

[0021]

In one embodiment of the semiconductor laser device of the first invention, a value of x of at least a portion in contact with a barrier layer of the guide layer is smaller than 0.4.

[0022]

In this embodiment, the Al mole fraction becomes lower in a region of the guide layer(s) closer to the well layer(s). Therefore, adverse effects of Al on the reliability can be prevented.

[0023]

In one embodiment of the semiconductor laser device of the first invention, the one or more well layers have a compressive strain.

[0024]

In this embodiment, a compressive strain is introduced to the well layer(s). Therefore, a reduction in threshold current can be achieved.

[0025]

In one embodiment of the semiconductor laser device of the first invention, the barrier layers have a tensile strain.

[0026]

In this embodiment, with a compressive strain introduced in the well layer(s) for reduction in threshold current, the barrier layers in which a tensile strain is introduced exhibit a strain-compensating function. Therefore, defects within crystals are reduced, and higher reliability can be obtained.

[0027]

There is also provided, according to a second invention, an optical disk unit in which the semiconductor laser device according to the first invention is used as a light-emitting device.

[0028]

In the optical disk unit with the above arrangement, the semiconductor laser device that operates with a higher optical power than hitherto is used as its light-emitting device for use of CD/MD. Therefore, data read-and-write operations are implementable even if the rotational speed of the optical disk is enhanced higher than before. In particular, the access time to optical disks, which has hitherto mattered in write operations to

CD-Rs, CD-RWs (CD-rewritables) or the like, can be reduced to a large extent.

[0029]

Mode for carrying out the invention:

Hereinbelow, this invention will be described in detail by way of embodiments thereof illustrated in the accompanying drawings.

[0030]

<First Embodiment>

Fig. 1 shows the structure of a semiconductor laser device according to an embodiment of the present invention. This embodiment relates to a semiconductor laser device with an oscillation wavelength of 780 nm having a quantum well active region of InGaAsP well layer/InGaP barrier layer as well as AlGaAs guide layers.

[0031]

Fig. 1 shows an n-type GaAs substrate 21, an n-type GaAs buffer layer (layer thickness: 0.5 μm) 22, an n-type $Al_{0.5}Ga_{0.5}As$ lower clad layer (layer thickness: 1.7 μm) 23, an $Al_{0.35}Ga_{0.65}As$ lower guide layer (layer thickness: 45 nm) 24, and an active region 25. In this case, the active region 25 has a double quantum well (DQW) structure composed of barrier layers 26 and well layers 27. There are also shown an $Al_{0.35}Ga_{0.65}As$ upper guide layer (layer thickness: 45 nm) 28, a p-type $Al_{0.5}Ga_{0.5}As$ first

upper clad layer (layer thickness: 0.2 μm) 29a, a p-type GaAs etching stopper layer (layer thickness: 3 nm) 30, a ridge-stripe shaped p-type $Al_{0.5}Ga_{0.5}As$ second upper clad layer (layer thickness: 1.28 μm) 29b, a p-type GaAs protective layer (layer thickness: 0.7 μm) 31, an n-type $Al_{0.7}Ga_{0.3}As$ first current blocking layer (layer thickness: 0.6 μm) 32, an n-type GaAs second current blocking layer (layer thickness: 0.7 μm) 33, a p-type GaAs buried protective layer (layer thickness: 0.6 μm) 34, a p-type GaAs cap layer (layer thickness: 2 μm) 35, an n-side electrode 36, and a p-side electrode 37.

[0032]

The barrier layers 26 each are formed of $In_{0.4}Ga_{0.6}P$, where the strain is -0.62% in tensile strain and the layer thickness is 8 nm for the barrier layers 26a and 26c and 7 nm for the layer 26b. It is noted that Eg of $In_{0.4}Ga_{0.6}P$ can be calculated as about 2.02 eV without consideration of strain, but it would be about 1.93 eV - 1.96 eV due to influences of tensile strain. The well layers 27 are each formed of $In_{0.162}Ga_{0.838}As_{0.671}P_{0.329}$, where Eg is 1.57 eV, there holds a lattice matching with the substrate, and the layer thickness is 5 nm for both of the layers 27a and 27b. It is noted that $|\Delta Eg|$ between the well layers 27 and the barrier layers 26 is 0.36 eV to 0.39 eV. Also, Eg of the AlGaAs guide layers 24, 28 is 1.86 eV.

[0033]

In this connection, in this AlGaAs-based semiconductor laser device, in which |ΔEg| between well layer and barrier layer is normally about 0.25 eV, a ΔEg value of about 0.20 eV would cause a carrier overflow, which could lead to a characteristic deterioration.

[0034]

The InGaAsP well layer/InGaP barrier layer/AlGaAs guide layer semiconductor laser device of the above constitution can be fabricated in the following manner. First, on a GaAs substrate 21 having (100) plane are formed through crystal growth by metal organic chemical vapor deposition process, one after another, a GaAs buffer layer 22, an AlGaAs lower clad layer 23, an AlGaAs lower guide layer 24, an active region 25 of a DQW structure composed of alternately disposed three barrier layers 26 and two well layers 27, an AlGaAs upper guide layer 28, an AlGaAs first upper clad layer 29a, a GaAs etching stop layer 30, an AlGaAs second upper clad layer 29b, and a GaAs protective layer 31. Further, a resist mask having a stripe along the (011) direction is formed by photolithographic process on the GaAs protective layer 31 at a portion where a ridge stripe is to be formed.

[0035]

Next, only the GaAs protective layer 31 and the

AlGaAs second upper clad layer 29b in the portions other than the resist mask are removed by etching, by which a ridge stripe portion is formed. Then, an AlGaAs first current blocking layer 32, a GaAs second current blocking layer 33, and a GaAs buried protective layer 34 are crystal-grown one after another on the whole ridge stripe portion including its upper side and both lateral sides by the metal organic chemical vapor deposition process. In this process, on the ridge stripe portion, the current blocking layers 32, 33 and the protective layer 34 are formed in a protrusive shape reflecting the shape of the ridge stripe portion.

[0036]

Next, a resist mask is formed over the GaAs buried protective layer 34 except the protrusive-shaped portion. Then, the protrusive-shaped buried protective layer 34, second current blocking layer 33 and first current blocking layer 32 are removed by etching one after another, thereby making a top portion of the ridge stripe portion exposed. Thereafter, a GaAs cap layer 35 is crystal-grown overall by metal organic chemical vapor deposition process. Finally, an n-side electrode 36 is formed on the surface of the substrate 21, and a p-side electrode 37 is formed on the surface of the cap layer 35. In this way, the semiconductor laser device of the InGaAsP

well layer/InGaP barrier layer/AlGaAs guide layer having a buried ridge structure whose stripe width is 2.5 μm is formed.

[0037]

Then, after subjecting the thus fabricated semiconductor laser device to cleaving at a resonator length of 800 μm, application of end-face reflective coating and mounting onto a stem, device characteristics were measured. As a result, the semiconductor laser device showed a threshold current of Ith = 38 mA and a temperature characteristic of T0 = 108K. Thus, as compared with the conventional semiconductor laser device with the InGaAsP-based quantum well structure in which no Al is contained in the well layers nor in the barrier layers, the semiconductor laser device of this embodiment can improve both the threshold current Ith and the temperature characteristic T0 at the same time in spite of the well layers 27 and the barrier layers 26 being similar to those in the semiconductor laser device of the InGaAsP-based quantum well structure. Reasons of this will be discussed below.

[0038]

(Desk Study of Ec, Ev)

Eg of semiconductor is a difference between the energy of conduction band (Ec) and the energy of valence

band (Ev). However, even with an identical Eg, Ec and Ev differ depending on the material type, the mole fraction or the like. It is generally said that the AlGaAs family are higher in Ec and Ev, whereas the InGaAsP family are lower in Ec and Ev. At an heterointerface between different semiconductor layers, a difference (ΔEc) between Ec's of the two layers or a difference (ΔEv) between their Ev's affects the behavior of electrons or carriers. Therefore, considerations are given to Ec and Ev for the composition of InGaAsP used in the well layers 27 and composition of AlGaAs used in the guide layer 24 in the semiconductor laser device of this embodiment, and their relationship is discussed below.

[0039]

In the following description, magnitudes of Eg, Ec and Ev of semiconductor will be expressed in terms of $|\Delta Eg0|$, $|\Delta Ec0|$ and $|\Delta Ev0|$, which are values of differences from reference values Eg, Ec and Ev of GaAs that is used in the substrate in both semiconductor laser devices. Also, it holds that $|\Delta Eg0| = |\Delta Ec0| + |\Delta Ev0|$. Here, the proportion of $|\Delta Ec0|$ in $|\Delta Eg0|$ is expressed as $|\Delta Ec0|/|\Delta Eg0|$.

[0040]

Then, with respect to $|\Delta Ec0|/|\Delta Eg0|$ of InGaP, a numerical value of

$|\Delta Ec0|/|\Delta Eg0| = 0.18$

is disclosed in Appl. Phys. Lett. 66, p. 1785 (1995), and this is used for discussions. Meanwhile, with respect to $|\Delta Ec0|/|\Delta Eg0|$ of GaAsP, its value is generally known to be larger than that of InGaP, but a specific numerical value is unknown. Therefore, several values are set as $|\Delta Ec0|/|\Delta Eg0|$ of GaAsP. Also with respect to InGaAsP, which has mole fractions between those of InGaP and GaAsP, a discussion is made below as to how $|\Delta Eg0|$, $|\Delta Ec0|$ and $|\Delta Ev0|$ of InGaAsP vary with various mole fractions, with an assumption that the values vary between the value of InGaP and the value of GaAsP depending on mole fractions. Here is shown a case where $|\Delta Ec0|/|\Delta Eg0|$ of GaAsP is 0.60, as an example most suited to actual GaAsP characteristics. Further, with respect to Eg itself of the InGaAsP family as well, the relationship with mole fractions were estimated based on experimental results. This is because although some relational expressions with mole fractions have already been posed for Eg of the InGaAsP family, those relational expressions are different from one another and have not yet been clarified. With respect to the $|\Delta Ec0|/|\Delta Eg0|$ of AlGaAs, it is generally said to be 0.6 to 0.65, and discussions were made with a value of 0.6 adopted.

[0041]

Fig. 4 is a view in which lines of constant Eg

values of InGaAsP are charted by connecting points (x, y) which hold the Eg values constant, on a plane on which the group-III Ga mole fraction is represented by the axis of abscissas, x, while the group-V P mole fraction is represented by the axis of ordinates, y. Fig. 5 is a view in which lines of constant Ec values are charted by connecting points (x, y), which hold the Ec values constant on a plane on which the group-III Ga mole fraction is represented by the axis of abscissas, x, while the group-V P mole fraction is represented by the axis of ordinates, y. It is noted that $|\Delta Ec0|$ is depicted at equal intervals of 50 meV. Also, Fig. 6 is a view in which lines of constant Ev values are charted by connecting points (x, y) which hold the Ev values constant, on a plane on which the group-III Ga mole fraction is represented by the axis of abscissas, x, while the group-V P mole fraction is represented by the axis of ordinates, y. It is noted that $|\Delta Ev0|$ is depicted at equal intervals of 50 meV. Fig. 7 is a view in which lines of constant strain values (lines of constant lattice constants) of GaAs are charted on a plane on which the group-III Ga mole fraction is represented by the axis of abscissas, x, while the group-V P mole fraction is represented by the axis of ordinates, y. In this connection, with respect to variations of Eg, Ec and Ev due to strain, an example of their evaluation on a case of

compressive strain of InGaP is disclosed in J. Appl. Phys., 54, 4, pp. 2052 - 2056 (1983). However, their variations due to various mole fractions of InGaAsP and GaAsP are unknown, and so influences of strain are not taken into consideration in Figs. 4 to 6.

[0042]

In comparison of the lines of constant Eg values, the lines of constant Ec values and the lines of constant Ev values, it can be understood that as the mole fractions approach InGaP along the lines of constant Eg values, |ΔEv0| increases, while |ΔEc0| decreases to some extent, so that Eg extends toward the valence band side. Conversely, it can be understood as the mole fractions approach GaAsP, |ΔEv0| decreases, while |ΔEc0| increases so that Eg extends toward the conduction band side.

[0043]

Fig. 8 shows a relationship among Ec and Ev values of InGaAsP and AlGaAs holding in lattice matching on the GaAs substrate. It can be seen that the InGaAsP materials are larger in |ΔEv0| and smaller in |ΔEc0| than AlGaAs materials. For the sake of comparison, Fig. 8 also shows data about $In_{0.4}Ga_{0.6}P$, which corresponds to the barrier layers 26 in this embodiment. It is noted that $In_{0.4}Ga_{0.6}P$ has a tensile strain of -0.64%, and an estimate in consideration of influence of strain for |ΔEc0|

is described in Fig. 8. This estimate is derived from reports on variations in Eg with compressively strained InGaP, and so the estimate value is merely a rule-of-thumb value.

[0044]

(Comparison between Desk-study Charts and the Embodiment, and Effects Found from Figs. 4 to 7)

Figs. 4 to 7 show mole fraction (x, y) points of the InGaAsP well layer 27 and the InGaP barrier layer 26 in the semiconductor laser device of this embodiment by ○ and ●, respectively. In this case, since the InGaP barrier layers 26 have tensile strain, it is considered that all of Eg, $|\Delta Ec0|$ and $|\Delta Ev0|$ would actually be smaller values. $|\Delta Ec0|$ can be read from Fig. 5, and $|\Delta Ev0|$ can be read from Fig. 6. Also, Fig. 8 shows mole fractions corresponding to the well layer 27, the guide layers 24, 28 and the barrier layer 26 by ①, ② and ③, respectively. Based on this, charting relationships among the energy bands of the GaAs substrate 21, the InGaAsP well layer 27, the InGaP barrier layer 26 and the AlGaAs guide layers 24, 28 result in a diagram shown in Fig. 3. Further, charting energy bands of the active region and its vicinity in the device structure of this embodiment result in a diagram shown in Fig. 2(a). In addition, energy bands of the conventional semiconductor laser device using InGaP guide layers are shown in Fig.

2(b), where the clad layers are of the composition of $Al_{0.5}Ga_{0.5}As$ in accordance with this embodiment.

[0045]

Referring to Figs. 2(a) and 2(b), comparison between the semiconductor laser device of this embodiment and the conventional semiconductor laser device clearly indicates that, in comparison of their guide layers with each other, the semiconductor laser device of this embodiment is smaller in terms of Eg of the guide layer than the conventional semiconductor laser device, but conversely larger in terms of $|\Delta Ec|$ of the well layer and the guide layer. Therefore, it can be presumed that the overflow of electrons from the InGaP barrier layers 26 was suppressed by the AlGaAs guide layers 24, 28, which led to a reduction in threshold current and an increase in temperature characteristic, as compared with the conventional semiconductor laser device having InGaP guide layers.

[0046]

(Determination of Effective Range for Mole Fractions of AlGaAs Guide Layer)

Figs. 5 and 6 are based on the assumption that $|\Delta Ec0|/|\Delta Eg0|$ of GaAsP is 0.60 as described above, and true curves are unknown. However, seeing that device characteristics obtained from the semiconductor laser

device of this embodiment and the conventional semiconductor laser device are not so much different from the presumptions by Figs. 5 and 6 as described above, it can be decided that the tendencies of the curves shown in Figs. 4 to 7 roughly represent the actualities.

[0047]

Now, based on this decision, the range of $|\Delta Ec0|$ that allows the composition of AlGaAs to effectively function as a guide layer will be described below.

[0048]

Considering that electrons are dominant in carrier overflow from the well layer, $|\Delta Ec0|$ is set so as not to be smaller than necessary. In the InGaAsP well layer in the semiconductor laser device having an oscillation wavelength of 780 nm, it is presumed that $|\Delta Ec0|$ is approx. 0.03 eV and $|\Delta Ev0|$ is approx. 0.12 eV. However, these values are not precise because they vary depending on the strain quantity of the well layer or the like.

[0049]

First, the minimum value of $|\Delta Ec0|$ needs to be set so that ΔEc between the guide layer and the well layer becomes about 0.12 eV or more, in order to prevent the overflow of electrons from the well layer. This value of 0.12 eV corresponds to a case where AlGaAs having a group-

III Al mole fraction of about 0.27 is used as the guide layer in a semiconductor laser device of 780 nm band having an AlGaAs well layer. In the case of the semiconductor laser device of this embodiment, since the well layers 27 are formed of InGaAsP with $|\Delta Ec0|$ = approx. 0.03 eV, it involves a condition that $|\Delta Ec0|$ of guide layers 24, 28 is larger than approx. 0.15 eV (= approx. 0.03 eV + 0.12 eV). Then, an AlGaAs corresponding to this $|\Delta Ec0|$ is an AlGaAs having an Al mole fraction larger than 0.20. This is, however, a value for ensuring a minimum necessary ΔEc, and it is desirable that an AlGaAs having an Al mole fraction of larger than 0.25 is used for the guide layers 24, 28 in order to more stably prevent the overflow of carriers.

[0050]

A maximum value of $|\Delta Ec0|$ is not particularly taken into consideration based on a reckoning that there would not much influence on electron injection unless a very large barrier is involved. In the case of the semiconductor laser device of this embodiment, a sufficient ΔEc has been obtained from the Al mole fraction of 0.35 of the guide layers 24, 28.

[0051]

(High Reliability by Being Al-Free)

In the present embodiment, since no Al is contained in the well layers 27 nor the barrier layers 26

touching the well layers 27, it is achievable to obtain high reliability even at high-temperature, high-power state. Even if the barrier layers 26 adjacent to the guide layers 24, 28 are eliminated so that the AlGaAs guide layers 24, 28 and the InGaAsP well layers 27 become adjacent to each other, respectively, there is a possibility that the overflow of carries from the well layers 27 can be suppressed. However, this is undesirable because using guide layers 24, 28 containing Al, which contains more impurities, as light-emitting layers or layers adjacent thereto would cause occurrence of non-radiative recombination, which would in turn accelerate the deterioration of crystals in the active region.

[0052]

Further, in this embodiment, outside the outermost barrier layers 26a, 26c in the quantum well active region are the guide layers 24, 28 of AlGaAs. However, 4 nm or less thicknesses of the InGaP barrier layers 26 would cause a decrease in reliability at high-temperature, high-power state. This could be attributed to an influence of Al of the guide layers 24, 28. Accordingly, making the thickness of the InGaP barrier layers 26 larger than 4 nm makes it possible to suppress the influence of Al of the guide layers 24, 28 to a large extent, so that high reliability can be obtained even at high-temperature, high-

power state.

[0053]

(Advantages of InGaAsP Well Layer Regarding Ec and Ev)

As can be seen from Fig. 3, as compared with the GaAs substrate 21, Eg of the InGaAsP well layers 27 extends toward the valence band side so that $|\Delta Ec0| < |\Delta Ev0|$. In contrast to this, Eg of the AlGaAs guide layers 24, 28 extends toward the conduction band side so that $|\Delta Ec0| > |\Delta Ev0|$. Accordingly, in regard to ΔEc and ΔEv between the well layer 27 and the guide layer 24, 28, a combination of the InGaAsP well layers 27 and the AlGaAs guide layers 24, 28 makes it possible to make |ΔEc| even larger and |ΔEv| even smaller, as compared with the case where, for example, AlGaAs is adopted for the well layers. That is, according to this embodiment, it becomes possible to enlarge |ΔEc| while |ΔEv| remains small by using the guide layer of a small Eg. Therefore, the effectiveness of this embodiment is produced by setting the Al mole fraction of the guide layers 24, 28 to at least larger than 0.20. It is noted that the Al mole fraction of the guide layers in such a case is smaller by 0.05 or more than the Al mole fraction of the guide layers of a semiconductor laser device of 780 nm band having AlGaAs well layers.

[0054]

In the semiconductor laser device of this embodiment, the Al mole fraction of the AlGaAs guide layers 24, 28 has been set to 0.35. However, the Al mole fraction needs only to be larger than 0.20, and may be lower than 0.35. In that case, whereas the effectiveness against the overflow of carriers lowers somewhat, it instead becomes possible to further suppress the deterioration of reliability due to Al.

[0055]

As shown above, in this embodiment, the active region 25 of the semiconductor laser device is provided in a DQW structure composed of barrier layers 26 and well layers 27, the barrier layers 26 being formed of InGaP and the well layers 27 being formed of $In_{0.162}Ga_{0.838}As_{0.671}P_{0.329}$ lattice-matched with GaAs substrate 21. Further, the guide layers 24, 28 are formed of $Al_{0.35}Ga_{0.65}As$. In the case where the guide layers 24, 28 are formed of AlGaAs like this, Eg of the guide layers would decrease as compared with the case where InGaP is used for the guide layers in the conventional manner, but $|\Delta Ec|$ between the well layer and the guide layer can be increased. Therefore, the overflow of electrons from the InGaP barrier layers 26 can be suppressed by the AlGaAs guide layers 24, 28. As a result, it becomes possible to achieve a reduction in threshold current and an improvement

in temperature characteristic over the semiconductor laser device with InGaP guide layers.

[0056]

Further, by the formation of the guide layers 24, 28 of an AlGaAs having an Al mole fraction larger than 0.20, ΔEc between the guide layers 24, 28 and the well layers 27 can be set to 0.12 eV or more, so that the overflow of electrons from the well layers 27 can be suppressed. Furthermore, by the combination with the InGaAsP well layers 27, the guide layers 24, 28 of a small Eg could enlarge |ΔEc| between the well layers 27 and the guide layers 24, 28 while |ΔEv| remains small. That is, barrier formation against the hole injection into the well layers 27 can be prevented and moreover the overflow of electrons from the well layers 27 can be suppressed.

[0057]

Consequently, as compared with the above-described conventional semiconductor laser device of InGaAsP-based quantum well structure in which no Al is contained in the well layers nor barrier layers and in which InGaP guide layers are used, the device characteristics of the present embodiment can be remarkably improved to a threshold current of Ith = 38 mA and a temperature characteristic of T0 = 108K, notwithstanding a similar constitution of the well layers 27 and the barrier

layers 26.

[0058]

In this connection, since the thickness of the InGaP barrier layers 26 is set larger than 4 nm, the influence of Al of the AlGaAs guide layers 24, 28 can be suppressed to a large extent, so that high reliability can be obtained in a high-temperature, high-power operation.

[0059]

(Degree of Freedom for Various Constitutions)

Although the InGaAsP well layers 27 have been set to the same lattice constant as that of the GaAs substrate 21 in this embodiment, yet the AlGaAs guide layers 24, 28 are also effective even if strain is applied to the InGaAsP well layers 27, in which case an improvement in device characteristics would result. Further, although the number of wells is two in layers in this embodiment, this is not limitative and similar effects can be obtained with any arbitrary number of wells. Furthermore, although this embodiment has been provided in a buried ridge structure, this is not limitative and similar effects can be obtained with any structure such as a ridge structure, an internal stripe structure and a buried heterostructure.

[0060]

Still also, although an n-type substrate has been used as the substrate in this embodiment, similar

effects can be obtained even if a p-type substrate is used and moreover the n-type and p-type of the individual layers are reversed. Further, although a wavelength of 780 nm has been adopted, this is not limitative and similar effects can be obtained only if the wavelength falls within a so-called 780 nm band which is larger than 760 nm and smaller than 800 nm.

[0061]

<Second Embodiment>

The present embodiment relates to a semiconductor laser device with an oscillation wavelength of 780 nm having a quantum well active region of InGaAsP well layers/GaAsP barrier layers as well as AlGaAs guide layers. The semiconductor laser device of this embodiment results from replacing InGaP by $GaAs_{0.72}P_{0.28}$ for the barrier layers 26 in the semiconductor laser device of the foregoing first embodiment, where the constitution except for the barrier layers and the manufacturing method are unchanged. Therefore, Fig. 1 for the first embodiment is used as it is in the following description.

[0062]

Regarding the $GaAs_{0.72}P_{0.28}$ barrier layers 26, the strain is -1% in tensile strain and the layer thickness is 8 nm for each of the layers 26a and 26c, and 7 nm for the layer 26b. Eg of $GaAs_{0.72}P_{0.28}$ can be calculated as

about 1.77 eV without consideration of strain. It is noted that influences of the tensile strain on Eg are not taken into consideration here because such influences are unclear as far as vicinities of the mole fractions of this material are concerned. The well layers 27 are formed of $In_{0.162}Ga_{0.838}As_{0.671}P_{0.329}$, with Eg being 1.57 eV, and there holds a lattice matching with the substrate, and the layer thickness is 5 nm for each of the layers 27a and 27b. It is noted that |ΔEg| between the well layers 27 and the barrier layers 26 is 0.20 eV. Also, Eg of the guide layers 24, 28 is 1.86 eV.

[0063]

After subjecting the obtained semiconductor laser device to cleaving at a resonator length of 800 μm, application of end-face reflective coating, and mounting onto a stem, device characteristics were measured. As a result, the semiconductor laser device showed a threshold current of Ith = 25 mA and a temperature characteristic of T0 = 140K. Thus, the semiconductor laser device using the GaAsP barrier layers with a tensile strain introduced therein is capable of remarkably improving the device characteristics in spite of a small ΔEg of 0.20 eV, compared with the semiconductor laser device of the first embodiment having InGaP barrier layers.

[0064]

(Advantages of GaAsP Barrier Layers, and Advantages of Use of AlGaAs Guide Layers in Combination)

Fig. 2(c) shows an energy band of the active region and its vicinities in the semiconductor laser device of this embodiment. In the case of the semiconductor laser device having InGaP barrier layers in the first embodiment, it can be understood that a very large barrier is formed on the Ev side against holes flowing from the guide layers 24, 28 to the well layers 27, as can be seen also from the energy band shown in Fig. 2(a). On the other hand, in the semiconductor laser device of GaAsP barrier layers in this embodiment, no barrier against the holes flowing from the guide layers to the well layers is present on the Ev side. In Figs. 4 to 7, the GaAsP composition of the barrier layers in this embodiment is shown by ▲. Since $|\Delta Ec0|/|\Delta Eg0|$ of GaAsP can be estimated as about 0.60 as stated before, $|\Delta Ev0|$ can be made much smaller, compared with InGaP, as can be seen from Fig. 6. Accordingly, using GaAsP instead of InGaP for the barrier layers allows ΔEv between the well layer and the barrier layer to be made smaller as well, so that the injection of holes into the well layers can be greatly improved.

[0065]

Therefore, it can be presumed that, according to this embodiment, carrier injection of both electrons and

holes was performed efficiently, leading to a reduction in threshold current.

[0066]

On the other hand, as can be seen from Figs. 4 and 5, |ΔEc0| of the GaAsP barrier layers increases in spite of a decrease in Eg, as compared with the case where InGaP is used. |ΔEc0| of the GaAsP barrier layers can be estimated as about 0.21 eV for the composition of $GaAs_{0.72}P_{0.28}$. Accordingly, since |ΔEc0| of the InGaAsP well layers 27 is about 0.03 eV as stated before, |ΔEc| between the well layer and the barrier layer results in about 0.18 eV (= 0.21 eV - 0.03 eV). This resulting value has a magnitude equivalent to that of the 780 nm band semiconductor laser device having AlGaAs well layers. However, although the GaAsP barrier layer, having a tensile strain of -1%, can be formed thin on both sides of the well layer, forming the guide layer of the same material at a thickness of several tens nm would cause occurrence of defects. Therefore, for the guide layer, there is a need for using a material that provides lattice matching with the GaAs substrate and that allows ΔEc to be set large. From these and other reasons, it is effective to use AlGaAs as the guide layer as in this embodiment.

[0067]

If InGaAsP having lattice matching with the

GaAs substrate was used as the guide layer, |ΔEc| between the well layer and the guide layer would result in a small value as can be seen also from Fig. 8. Although |ΔEc| between well layer and barrier layer would be large enough, the barrier layer is so thin in thickness that electrons would early overflow, making it impossible to obtain successful characteristics.

[0068]

The $Al_{0.35}Ga_{0.65}As$ guide layers 24, 28 in the semiconductor laser device of this embodiment have a |ΔEc0| value of about 0.26 eV, which can be estimated to be even higher than that of the barrier layers. Therefore, quite a high effectiveness for the suppression of carrier overflow can be obtained, so that the temperature characteristic T0 can be improved.

[0069]

By way of comparison, in the case of the AlGaAs-based semiconductor laser device, when $Al_{0.35}Ga_{0.65}As$ is used for the barrier layer and the guide layer, ΔEc between the well layer and the barrier layer/guide layer is estimated to be about 0.18 eV. That is, even with $Al_{0.35}Ga_{0.65}As$ used similarly, the present embodiment provides a larger ΔEc between the well layer and the guide layer. This is an effect produced by using InGaAsP for the well layer, as described also in connection

with the first embodiment.

[0070]

(Determination of Effective Range for GaAsP Barrier Layer)

In the present embodiment, $GaAs_{0.72}P_{0.28}$ is used for the barrier layers for improvement of characteristics over the first embodiment. In this case, using GaAsP and InGaAsP of appropriate mole fraction ranges for the barrier layers allows a sufficient effect to be obtained.

[0071]

Now, upper limits and lower limits of $|\Delta Ec0|$ and $|\Delta Ev0|$ that allow InGaAsP to effectively function as a barrier layer will be described below. Considering that holes are dominant in carrier injection into the well layer, $|\Delta Ev0|$ is set so as not to be larger than necessary. Also, considering that electrons are dominant in carrier overflow from the well layer, $|\Delta Ec0|$ is set so as not to be smaller than necessary. In addition, in the InGaAsP well layer in the semiconductor laser device having an oscillation wavelength of 780 nm, it is presumed that $|\Delta Ec0|$ = approx. 0.03 eV and $|\Delta Ev0|$ = approx. 0.12 eV. However, these values are not precise because they vary depending on the strain quantity of the well layer or the like.

[0072]

First, as to the minimum value of $|\Delta Ev0|$, ΔEv between the barrier layer and the well layer needs to become at least a positive value. Therefore, $|\Delta Ev0| >$ approx. 0.12 eV, and it can be said from Fig. 6 that there is a boundary for $|\Delta Ev0|$ in the vicinity of P mole fractions of 0.15 to 0.30.

[0073]

Next, the maximum value of $|\Delta Ev0|$ needs to be suppressed to such an extent that the injection of holes from the guide layers is not blocked. Whereas various types of materials or compositions to be lattice-matched with the GaAs substrate, such as InGaP or AlGaAs, are used for guide layers or clad layers, the value of $|\Delta Ev0|$ at least needs to be smaller than in the case where InGaP involving the largest $|\Delta Ev0|$ is used, and it results that $|\Delta Ev0|$ is smaller than approx. 0.38 eV (a value of $|\Delta Ev0|$ at an intersecting point between the broken line indicating that the strain quantity for GaAs is 0 and the line of InGaP in Fig. 6). Accordingly, it can be said from Fig. 6 that there is a boundary of $|\Delta Ev0|$ in the vicinity of P mole fractions of 0.60 to 0.80.

[0074]

Also, the minimum value of $|\Delta Ec0|$ needs to be set so that ΔEc between the barrier layer and the well layer becomes about 0.12 eV or more, in order to prevent

the overflow of electrons from the well layer. This value of 0.12 eV corresponds to a case where AlGaAs having a group-III Al mole fraction of about 0.27 is used as the barrier layer in an AlGaAs-based semiconductor laser device. Therefore, since $|\Delta Ec0|$ of the well layers is approx. 0.03 eV, $|\Delta Ec0|$ of the barrier layers is larger than approx. 0.15 eV (= approx. 0.03 eV + 0.12 eV). As can be seen from Figs. 5 and 7, the lines of constant Ec values are nearly parallel to the lines of constant lattice constants, and therefore the boundary for $|\Delta Ec0|$ can be set by a value of difference of a strain quantity against GaAs of the barrier layers from a strain quantity of the well layers against GaAs. That is, it can be said that there is a boundary of $|\Delta Ec0|$ in the vicinity of points where the difference in strain quantity from the well layers is -0.65% to -0.85%.

[0075]

By the presence of the AlGaAs guide layers 24, 28, the semiconductor laser device of this embodiment is so structured as to be free from any problem in terms of carrier overflow from the guide layers 24, 28 to the outside. However, increasing the ΔEc between the barrier layers 26 and the well layers 27 as described above makes it possible to suppress the overflow of more than necessary amounts of carriers to the layers containing Al, so that even higher reliability can be obtained as compared with

the case of the first embodiment.

[0076]

Next, the maximum value of |ΔEc0| is not particularly taken into consideration based on a reckoning that electron injection would not be affected very much unless a very large barrier is involved.

[0077]

As shown above, according to the results of measurement of characteristics on semiconductor laser devices using several types of barrier layers that were actually fabricated based on the roughly estimated P mole fractions and the boundary of strain quantity, it follows that a range of P mole fractions larger than 0.2 and smaller than 0.75 for the barrier layers is effective. Further, a range of P mole fractions larger than 0.25 and smaller than 0.6 allows quite effective device characteristics to be obtained. Also, setting the difference in strain quantity of the barrier layers from the well layers to -0.65% or less would cause the device characteristics to be deteriorated. Therefore, an effective range of the difference of strain quantity of the barrier layers from the strain quantity of the well layers is larger than -0.65%.

[0078]

It is noted that the aforementioned estimate

values of $|\Delta Eg0|$, $|\Delta Ec0|$ and $|\Delta Ev0|$ are not necessarily true values, since changes in band structure due to strain are not taken into consideration because of the absence of definite data. Nevertheless, the ranges described above have been obtained from the results of discussions on the characteristics of semiconductor laser devices that were actually fabricated by referencing those estimations. Therefore, the above ranges are not conditioned on whether those estimations are true or not.

[0079]

As described above, in the present embodiment, the composition of the barrier layers 26 in the semiconductor laser device of the first embodiment is changed from InGaP to $GaAs_{0.72}P_{0.28}$ with a strain quantity of -1% introduced therein, thus providing a semiconductor laser device having a quantum well active region of InGaAsP well layers and GaAsP barrier layers, and AlGaAs guide layers. Like this, the barrier layers 26 are formed of a GaAsP having a P mole fraction larger than 0.2 and smaller than 0.75 and having a strain-quantity difference of more than -0.65% from the strain quantity of well layers (= strain quantity of substrate), and further the barrier layers 26 are combined with the InGaAsP well layers 27. As a result of this, $|\Delta Ev0|$ of the barrier layers 26, the well layers 27 and the guide layers 24, 28 can be set so as to

meet a relationship of magnitude that |ΔEv0| of well layers 27 < |ΔEv0| of barrier layers 26 < |ΔEv0| of guide layers 24, 28, thus making it possible to efficiently achieve the injection of holes from the guide layers 24, 28. Moreover, ΔEc between the barrier layers 26 and the well layers 27 is settable to 0.12 eV or more, so that the overflow of electrons from the well layers 27 is suppressed.

[0080]

Thus, as compared with the case using the InGaP barrier layers, the device characteristics are remarkably improved to a threshold current of Ith = 25 mA and a temperature characteristic of T0 = 140K, in spite of ΔEg between the well layer 27 and the barrier layer 26 as small as 0.20 eV.

[0081]

(Degree of Freedom for Various Constitutions)

Although the InGaAsP well layers 27 have been set to the same lattice constant as that of the GaAs substrate 21 in this embodiment, yet the GaAsP barrier layers 26 are also effective even if strain is applied to the InGaAsP well layers 27, in which case an improvement in device characteristics would result. Further, although the number of wells is two in layers in this embodiment, this is not limitative and similar effects can be obtained with any arbitrary number of wells. Furthermore, although this

embodiment has been provided in a buried ridge structure, this is not limitative and similar effects can be obtained with any structure such as a ridge structure, an internal stripe structure and a buried heterostructure.

[0082]

Still also, although an n-type substrate has been used as the substrate in this embodiment, similar effects can be obtained even if a p-type substrate is used and moreover the n-type and p-type of the individual layers are reversed. Further, although a wavelength of 780 nm has been adopted, this is not limitative and similar effects can be obtained only if the wavelength falls within a so-called 780 nm band covering a range of larger than 760 nm and smaller than 800 nm.

[0083]

<Third Embodiment>

Fig. 9 shows the structure of a semiconductor laser device according to the present embodiment. This embodiment relates to a semiconductor laser device with a wavelength of 780 nm having an InGaAsP compressively strained well layer/InGaAsP barrier layer quantum well active region and AlGaAs guide layers.

[0084]

Fig. 9 shows an n-type GaAs substrate 41, an n-type GaAs buffer layer (layer thickness: 0.5 μm) 42, an n-

type $Al_{0.4}Ga_{0.6}As$ lower second clad layer (layer thickness: 3.0 µm) 43a, an n-type $Al_{0.5}Ga_{0.5}As$ lower first clad layer (layer thickness: 0.2 µm) 43b, an $Al_{0.42}Ga_{0.58}As$ lower second guide layer (layer thickness: 70 nm) 44a, an $Al_{0.32}Ga_{0.68}As$ lower first guide layer (layer thickness: 10 nm) 44b, and an active region 45. In this case, the active region 45 has a DQW structure composed of barrier layers 46 and well layers 47. There are also shown an $Al_{0.32}Ga_{0.68}As$ upper first guide layer (layer thickness: 10 nm) 48a, an $Al_{0.42}Ga_{0.58}As$ upper second guide layer (layer thickness: 70 nm) 48b, a p-type $Al_{0.5}Ga_{0.5}As$ first upper clad layer (layer thickness: 0.2 µm) 49a, a p-type GaAs etching stopper layer (layer thickness: 3 nm) 50, a ridge-stripe shaped p-type $Al_{0.5}Ga_{0.5}As$ second upper clad layer (layer thickness: 1.28 µm) 49b, a p-type GaAs protective layer (layer thickness: 0.7 µm) 51, an n-type $Al_{0.7}Ga_{0.3}As$ first current blocking layer (layer thickness: 0.6 µm) 52, an n-type GaAs second current blocking layer (layer thickness: 0.7 µm) 53, a p-type GaAs buried protective layer (layer thickness: 0.6 µm) 54, a p-type GaAs cap layer (layer thickness: 2 µm) 55, an n-side electrode 56, and a p-side electrode 57.

[0085]

The barrier layers 46 are formed of

$In_{0.126}Ga_{0.874}As_{0.407}P_{0.593}$, where Eg is 1.98 eV, the strain is -1.20% in tensile strain and the layer thickness is 10 nm for each of the layers 46a and 46c and 5 nm for the layer 46b. The well layers 47 are formed of $In_{0.27}Ga_{0.73}As_{0.55}P_{0.45}$, where Eg is 1.55 eV, the strain is 0.35% in compressive strain and the layer thickness is 8 nm for each of the layers 47a and 47b. It is noted that $|\Delta Eg|$ between the well layers 47 and the barrier layers 46 is 0.43 eV.

[0086]

Eg of the guide layers 44b, 48a is 1.82 eV, and Eg of the guide layers 44a, 48b is 1.95 eV. It is noted that the influence of the strain on Eg of the barrier layers 46 and the well layers 47 is not taken into consideration in this embodiment as well because such influence is unclear also with respect to the compositions of the materials used in this embodiment.

[0087]

The semiconductor laser device with the above-described InGaAsP compressive-strain well layer/InGaAsP barrier layer/AlGaAs guide layer structure can be fabricated by forming a buried ridge structure with a stripe width of 2 μm by the crystal growth techniques and procedures similar to those used in the first embodiment. Then, after subjecting the thus obtained semiconductor

laser device to cleaving at a resonator length of 800 μm, application of end-face reflective coating and mounting onto a stem, device characteristics were measured. As a result, the semiconductor laser device showed a threshold current of Ith = 30 mA and a temperature characteristic of T0 = 153K. Thus, the semiconductor laser device having the well layers with a compressive strain introduced therein and using the InGaAsP barrier layers can also obtain successful device characteristics.

[0088]

Fig. 10(a) shows an energy band of the active region and its vicinity in the semiconductor laser device of the present embodiment. In this semiconductor laser device, each of the AlGaAs guide layers 44, 48 is formed in a two-layer structure. Further, for the guide layers 44b, 48a closer to the well layers 47, the Al mole fraction is made 0.32, which is smaller then that of the guide layers 24, 28 of the foregoing first and second embodiments. Like this, the Al mole fraction in the region close to the well layers 47 that are light-emitting layers are made small, by which the reliability is further improved. Meanwhile, the Al mole fraction of the guide layers 44a, 48b farther from the well layers 47 is set to 0.42, which is larger than that of the guide layers 24, 28 of the first and second embodiments, so that |ΔEc0| and |ΔEv0| go larger in the

order from the well layers 47 side toward the clad layers 43, 49 side. Accordingly, the overflow of carriers can be suppressed within the guide layers 44, 48, so that a temperature characteristic T0 generally equal to that of the semiconductor laser device of the second embodiment can be obtained.

[0089]

In this semiconductor laser device, since the barrier layers 46 are formed of InGaAsP having a P mole fraction of smaller than 0.60, $|\Delta Ec|$ between the well layers 47 and the barrier layers 46 can be increased while $|\Delta Ev|$ remains small, as compared with the semiconductor laser device of the first embodiment using InGaP for the barrier layers.

[0090]

As can be seen from Figs. 5 and 6, around the mole fractions of the barrier layers 46 of this semiconductor laser device, the way the lines of constant Ec values vary with mole fractions largely differs from the way the lines of constant Ev values vary with mole fractions. Therefore, selecting appropriate mole fractions will make it possible to control $|\Delta Ec0|$ and $|\Delta Ev0|$ of the barrier layers 46 independently from each other to some extent. For example, since the lines of constant Ec values are generally parallel to the lines of constant lattice

constants, it is also possible to change Ev while Ec and strain quantity of the barrier layers 46 are kept almost unchanged. In this embodiment, the In mole fraction and the P mole fraction are adjusted so that $|\Delta Ev|$ between the well layers 47 and the barrier layers 46 becomes larger as compared with that of the semiconductor laser device of the second embodiment. As a result of this, it also becomes possible to improve the confinement of holes into the well layers 47.

[0091]

Also, in this embodiment, an InGaAsP having a compressive strain of 0.35% is used for the well layers 47, so that a strain effect for lower threshold current can be obtained. In this connection, the quantum well active region has a strain compensation structure composed of the well layers 47 with a compressive strain introduced therein and the barrier layers 46 with a tensile strain of -1.20% introduced therein. Therefore, an average strain quantity of the whole active region can be suppressed, so that the quantity of defects within crystals can be reduced as compared with the case where the well layers are held in lattice matching with the substrate, thus allowing a further improvement in reliability to be achieved. Also, as a result of the reduction in average strain quantity, the critical layer thickness of the whole quantum-well-

layer active region is increased, whereby the barrier layers 46a, 46b are each set to as large a layer thickness as 10 nm, compared with 8 nm of the second embodiment. Further, since the distance from the well layers 47 to the corresponding AlGaAs guide layers 44, 48 is set to as large as 10 nm, the influence of Al in the guide layers 44, 48 on the active region can be further reduced, which allows high reliability to be obtained even at a high-temperature, high-power state. Furthermore, in this embodiment, since the barrier layers 46 are provided by In-added layers of InGaAsP, it has become possible to obtain even higher reliability by suppressing the growth of dislocations by virtue of In.

[0092]

It is noted that the guide layers 44, 48 in the semiconductor laser device of the above constitution are two-layer structured, so that the Al mole fraction is increased in two steps from the quantum-well active region side to the clad layers 43, 49 side. However, alternatively, the Al mole fraction may also be increased continuously from the quantum-well active region side to the clad layers 43, 49 side. An example of the energy band in such a case is shown in Fig. 10(b). In Fig. 10(b), the Al mole fraction of the AlGaAs guide layers 44, 48 is increased from 0.32 to 0.5, the latter value being equal to

the Al mole fraction of the clad layers 43b, 49. In this case, also, the overflow of carriers can be suppressed sufficiently.

[0093]

However, the Al mole fraction of the guide layers 44, 48 in that case is, desirably, made smaller than 0.4 at least for the portions adjacent to the barrier layers 46. This is because higher Al mole fractions in vicinities of the well layers 47 would adversely affect the reliability.

[0094]

In this embodiment, the active region is provided by the combined InGaAsP compressive-strained well layers and InGaAsP tensile-strained barrier layers. However, the active region is not limited to this combination. It is also possible to adopt a combination of InGaAsP strain-free well layers and InGaAsP tensile-strained barrier layers, a combination of InGaAsP compressive-strain well layers and GaAsP barrier layers, etc. Further, although the number of well layers in this embodiment is two, this is not limitative and similar effects can be obtained with any arbitrary number of well layers. Furthermore, although this embodiment has been provided in a buried ridge structure, this is not limitative and similar effects can be obtained with any

structure such as a ridge structure, an internal stripe structure and a buried heterostructure.

[0095]

Still also, although an n-type substrate has been used as the substrate in this embodiment, similar effects can be obtained even if a p-type substrate is used and moreover the n-type and p-type of the individual layers are reversed. Further, although a wavelength of 780 nm has been adopted, this is not limitative and similar effects can be obtained only if the wavelength falls within a so-called 780 nm band which covers a range of larger than 760 nm and smaller than 800 nm.

[0096]

<Fourth Embodiment>

This embodiment relates to an optical disk unit using the semiconductor laser device according to any one of the foregoing embodiments. Fig. 11 is a structural view of the optical disk unit of this embodiment. This optical disk unit operates to write data on an optical disk 61 or reproduce data written on the optical disk 61. In this optical disk unit, a semiconductor laser device 62 according to any one of the foregoing individual embodiments is included as a light-emitting device for use in those operations.

[0097]

The configuration and operations of this optical disk unit will be described below. In this optical disk unit, for write operations, signal light (a laser beam with a data signal superimposed thereon) emitted from the semiconductor laser device 62 passes through a collimator lens 63, becoming parallel light, and is transmitted by a beam splitter 64. Then, after its polarized state is adjusted by a $\lambda/4$ polarizer 65, the signal light is converged by a laser-beam irradiation objective lens 66 to thereby irradiate the optical disk 61. In this way, by the laser beam with a data signal superimposed thereon, data is written onto the optical disk 61.

[0098]

For read operations, a laser beam emitted from the semiconductor laser device 62 with no data signal superimposed on the laser beam travels along the same path as in the write operation, irradiating the optical disk 61. Then, the laser beam reflected by the surface of the optical disk 61, on which data has been recorded, passes through the laser-beam irradiation objective lens 66 and the $\lambda/4$ polarizer 65, and is thereafter reflected by the beam splitter 64 so as for its traveling direction to be changed by 90°. Subsequently, the laser beam is focused by a reproduction-light objective lens 67 and applied to a signal-detection use photodetector device 68. Then, in the

signal-detection use photodetector device 68, a data signal read from the optical disk 61 is transformed into an electric signal according to the intensity of the incident laser beam, and reproduced to the original information signal by a signal-light reproduction circuit 69.

[0099]

The optical disk unit of this embodiment employs the semiconductor laser device 62, as described above, which operates with higher optical power than conventional. Therefore, data read-and-write operations are implementable even if the rotational speed of the optical disk 61 is enhanced higher than conventional. Accordingly, the access time to optical disks, which has hitherto mattered in write operations particularly to CD-Rs, CD-RWs or the like, can be reduced to a large extent. This makes it feasible to provide an optical disk unit which realizes more comfortable operations.

[0100]

This embodiment has been described on a case where the semiconductor laser device according to any of the foregoing embodiments is applied to a recording and playback type optical disk unit. However, this invention is not limited to this, and needless to say, applicable also to optical-disk recording units or optical-disk playback units in which a semiconductor laser device of the

780 nm wavelength band is used as a light-emitting device.

[0101]

Effect of the invention:

As is apparent from the above description, in the semiconductor laser device with an oscillation wavelength of 780 nm of the first invention, said one or more well layers and said barrier layers are formed of any one of InGaP, InGaAsP and GaAsP, and said guide layers are formed of $Al_zGa_{1-z}As$ $(0.20<z\leq1)$. Therefore, $|\Delta Ec|$ between the well layer and the guide layer can be set to about 0.12 eV or larger, which corresponds to a value of ΔEc between the barrier layer and the well layer resulting when AlGaAs is used as the barrier layer. Therefore, the overflow of electrons from the well layer is suppressed.

[0102]

That is, according to this invention, the overflow of electrons from the well layer, which has been a cause of poor characteristics in the semiconductor laser device using the InGaP guide layer, can be solved, so that the characteristics of the semiconductor laser device of the 780 nm band containing no Al in the active region are improved remarkably. Furthermore, by virtue of the presence of the barrier layer containing no Al, the well layer is never neighbored in contact by the AlGaAs guide layer containing Al. Thus, high reliability is ensured.

[0103]

In the semiconductor laser device of one embodiment, because a value of x is set larger than 0.25, $|\Delta Ec|$ between the AlGaAs guide layer and the well layer is securely made larger than 0.12 eV, and the overflow of electrons from the well layer(s) can be suppressed reliably.

[0104]

In the semiconductor laser device of one embodiment, a value of x is smaller than a value of an Al mole fraction of the upper and lower clad layers. Therefore, $|\Delta Ec0|$ and $|\Delta Ev0|$ of the AlGaAs guide layer can be made smaller than those of the lower clad layer and the upper clad layer. Therefore, the overflow of electrons is suppressed in the guide layer(s), so that the temperature characteristic can be improved.

[0105]

In the semiconductor laser device of one embodiment, the value of x varies stepwise or continuously and in such a fashion as to increase with increasing nearness to the upper and lower clad layers. Therefore, $|\Delta Ec0|$ and $|\Delta Ev0|$ of the AlGaAs guide layer(s) increase more and more from the well layer side toward the lower clad layer and upper clad layer side. Therefore, the overflow of electrons is suppressed more reliably in the guide layers.

[0106]

In the semiconductor laser device of one embodiment, since a value of x of at least a portion in contact with a barrier layer of the guide layer is smaller than 0.4, the Al mole fraction becomes lower in a region of the guide layer(s) closer to the well layer(s). Therefore, adverse effects of Al on the reliability can be prevented.

[0107]

In the semiconductor laser device of one embodiment, a compressive strain is introduced to the well layer(s). Therefore, a reduction in threshold current can be achieved.

[0108]

In the semiconductor laser device of one embodiment, a tensile strain is introduced to the barrier layers. Therefore, with a compressive strain introduced to the well layer(s) for reduction in threshold current, the barrier layers in which a tensile strain is introduced compensate the strain in the well layer(s). Therefore, defects within crystals are reduced, and higher reliability can be obtained.

[0109]

In an optical disk unit of the second invention, the semiconductor laser device of the first invention that operates with a higher optical power than hitherto is used

as a light-emitting device. Therefore, data read-and-write operations are implementable even if the rotational speed of the optical disk is enhanced higher than before. In particular, the access time to optical disks, which has hitherto mattered in write operations to CD-Rs, CD-RWs (CD-rewritables) or the like, can be reduced to a large extent.

Brief explanation of the drawings:

Fig. 1 shows the structure of a semiconductor laser device according to the present invention.

Fig. 2 shows energy bands of the active region and its vicinity in the semiconductor laser device shown in Fig. 1 and in semiconductor laser devices having different barrier layer structures, respectively.

Fig. 3 shows a relationship among the energy bands of the GaAs substrate, the InGaAsP well layer, the InGaP barrier layer, and the AlGaAs guide layer in Fig. 1.

Fig. 4 shows lines of constant Eg values of InGaAsP.

Fig. 5 shows lines of constant Ec values of InGaAsP.

Fig. 6 shows lines of constant Ev values of InGaAsP.

Fig. 7 shows lines of constant lattice constants of InGaAsP.

Fig. 8 shows a relationship among Ec and Ev

values of GaAs, InGaAsP and AlGaAs providing lattice matching with the GaAs substrate and of $In_{0.4}Ga_{0.6}P$.

Fig. 9 shows the structure of a semiconductor laser device other than that of Fig. 1.

Fig. 10 shows energy bands of the active region and its vicinity in the semiconductor laser device shown in Fig. 9.

Fig. 11 is a structural view of an optical disk unit according to the present invention.

Fig. 12 shows the structure of a conventional InGaAsP quantum well semiconductor laser device in which no Al is contained in the well layers and barrier layers.

Fig. 13 shows an energy band gap (Eg) of the active region and its vicinity in the semiconductor laser device shown in Fig. 12.

Explanation of numerals:

21, 41···GaAs substrate

22, 42···GaAs buffer layer

23···AlGaAs lower clad layer

24··· AlGaAs lower guide layer

25, 45···active region

26···InGaP barrier layer

27, 47···InGaAsP well layer

28···AlGaAs upper guide layer

29a, 49a···AlGa first upper clad layer

29b, 49b··· AlGa second upper clad layer

30, 50···GaAs etching stopper layer

31, 51···GaAs protective layer

32, 52···AlGaAs first current blocking layer

33, 53···GaAs second current blocking layer

34, 54···GaAs buried protective layer

35, 55···GaAs cap layer

36, 56···n-side electrode

37, 57···p-side electrode

43a···AlGaAs lower second clad layer

43b···AlGaAs lower first clad layer

44a···AlGaAs lower second guide layer

44b···AlGaAs lower first guide layer

46···InGaAsP barrier layer

48a···AlGaAs upper first guide layer

48b···AlGaAs upper second guide layer

61···optical disc

62···semiconductor laser device

63···collimator lens

64···beam splitter

65···λ/4 polarizer

66···laser-beam irradiation objective lens

67···reproduction-light-objective lens

68···signal-detection use photodetector device

69···signal-light reproduction circuit

Document name: Drawings

Fig. 1

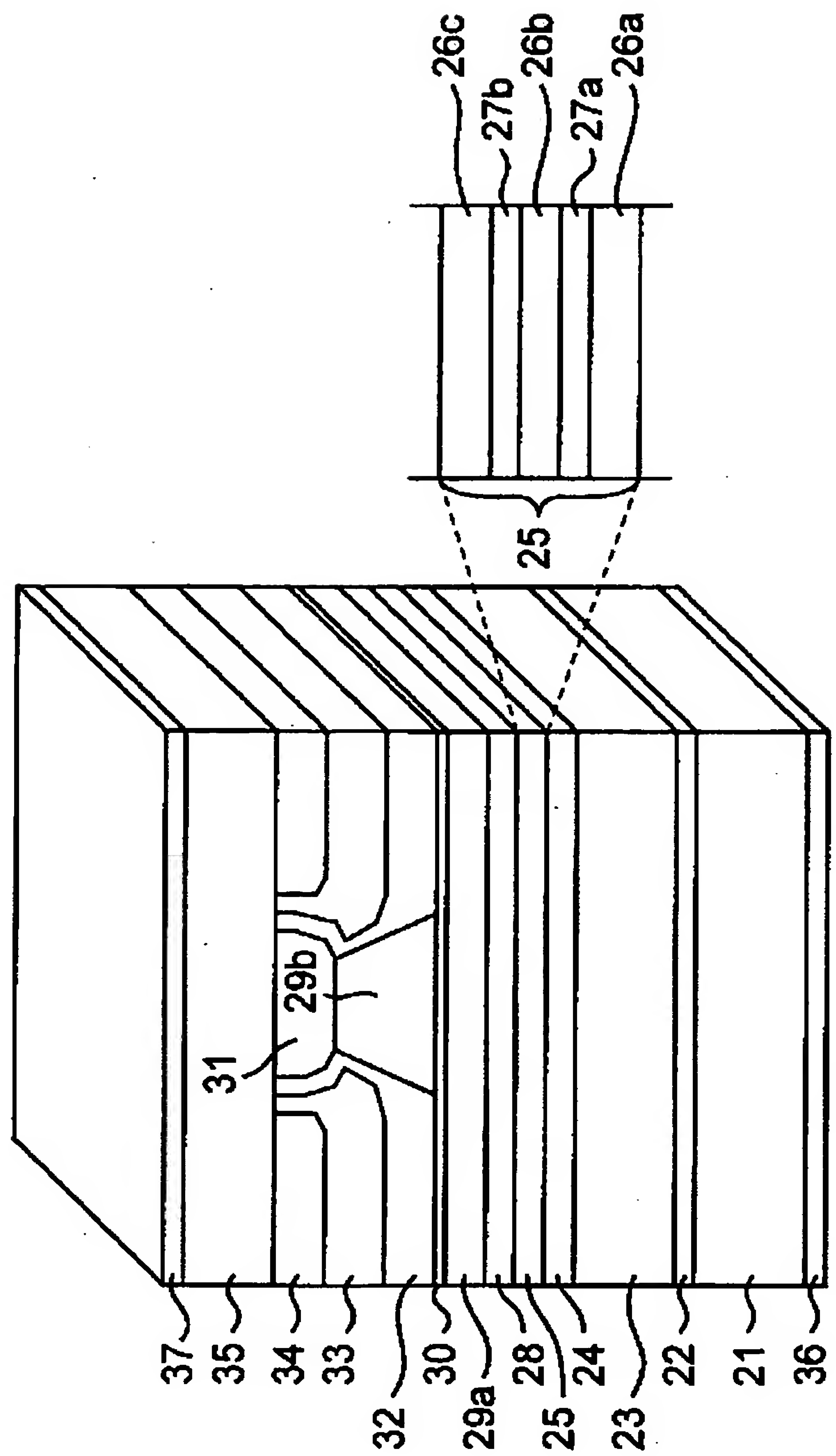
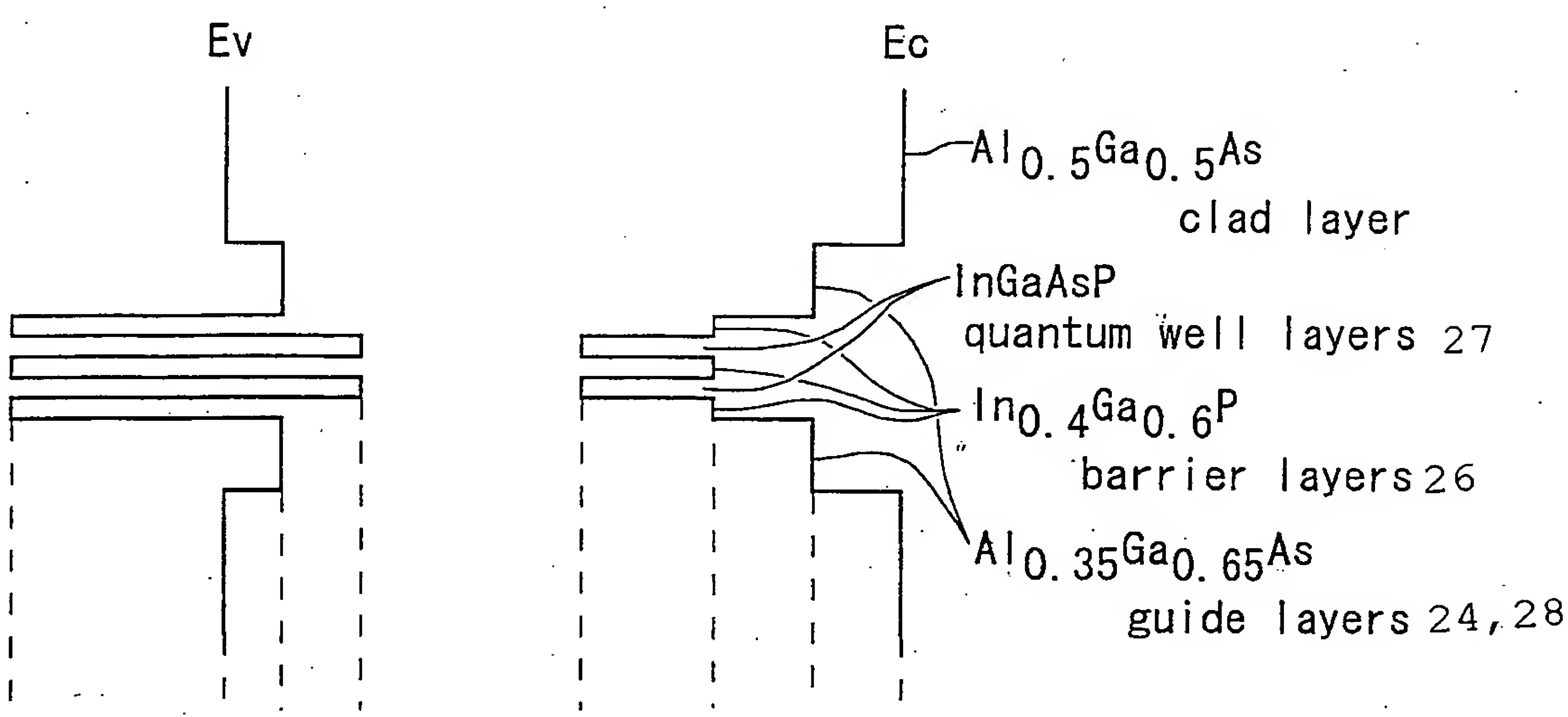
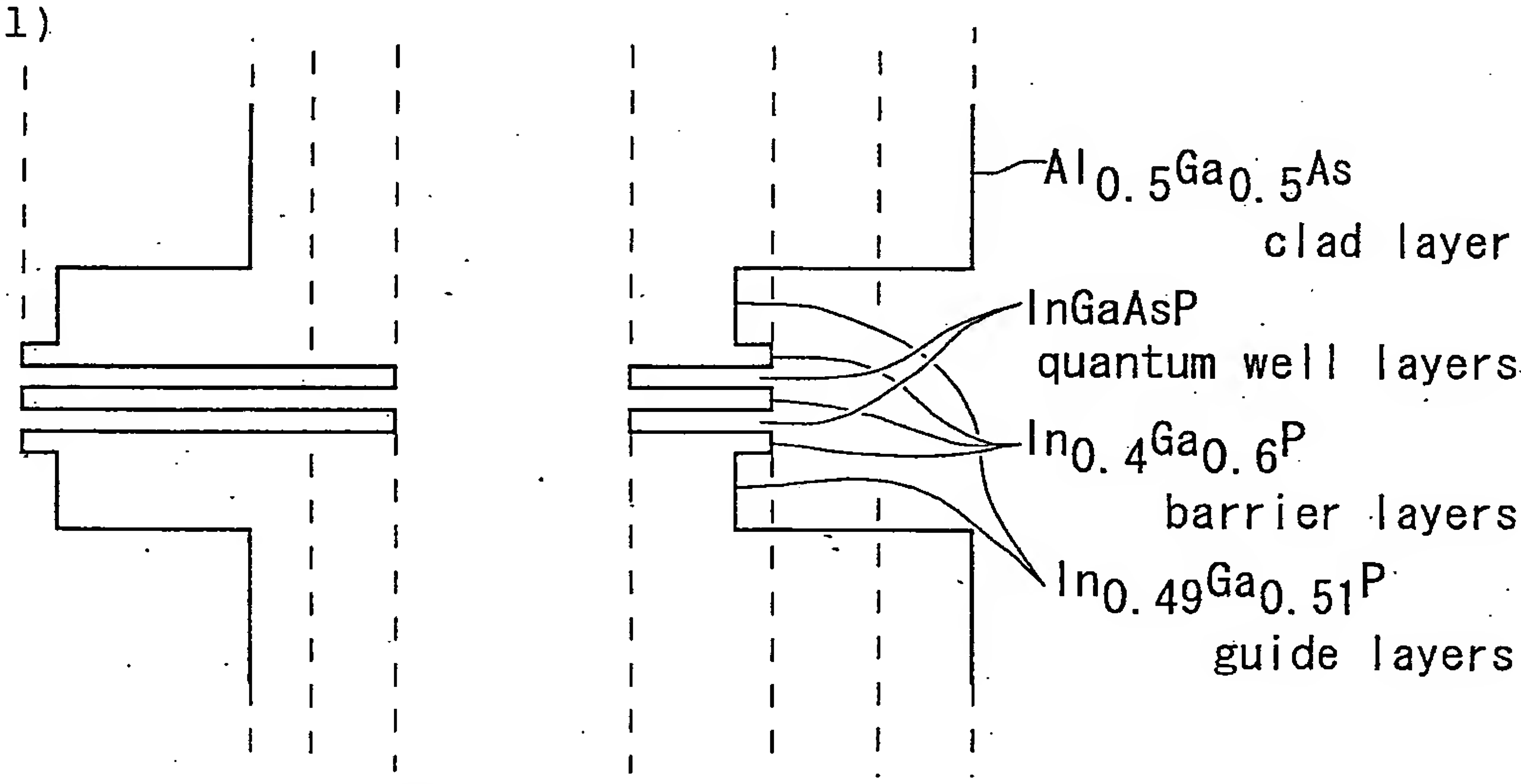


Fig. 2

(a) InGaAsP well layer/InGaP barrier layer/AlGaAs guide layer
(First Embodiment)



(b) InGaAsP well layer/InGaP barrier layer/InGaP guide layer
(Conventional)



(c) InGaAsP well layer/GaAsP barrier layer/AlGaAs guide layer
(Second Embodiment)

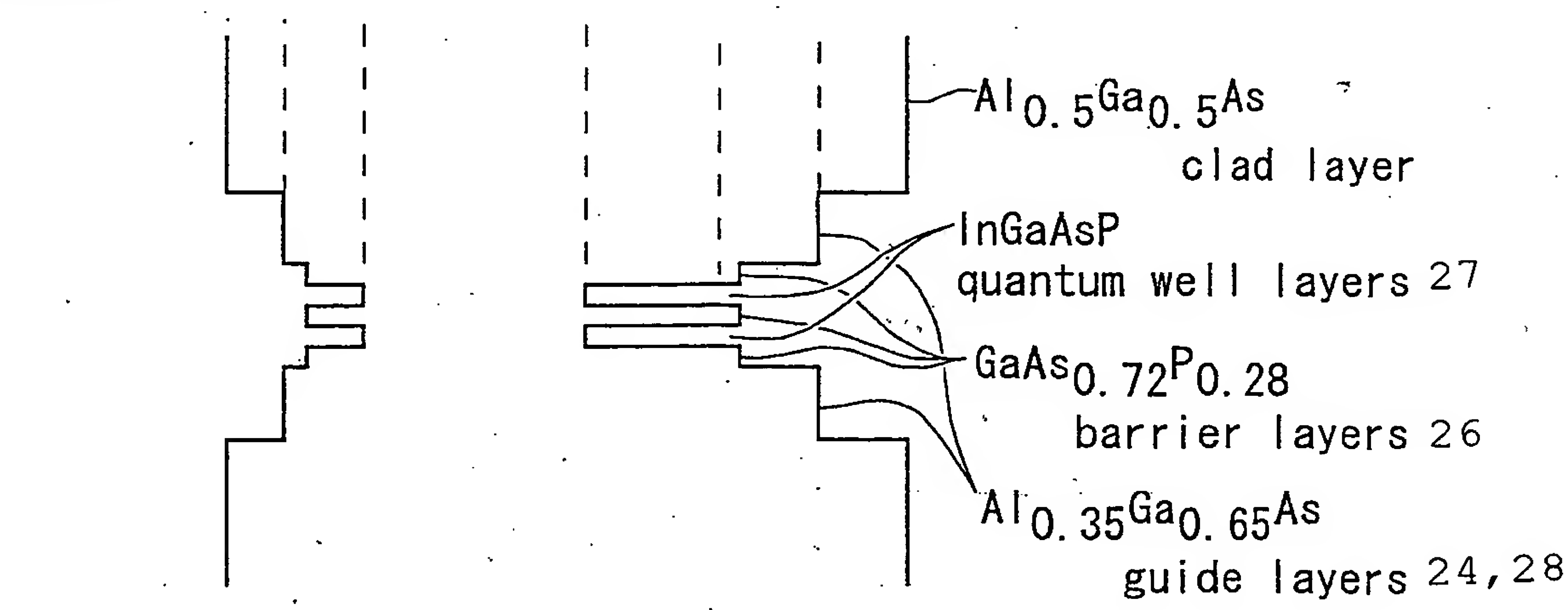
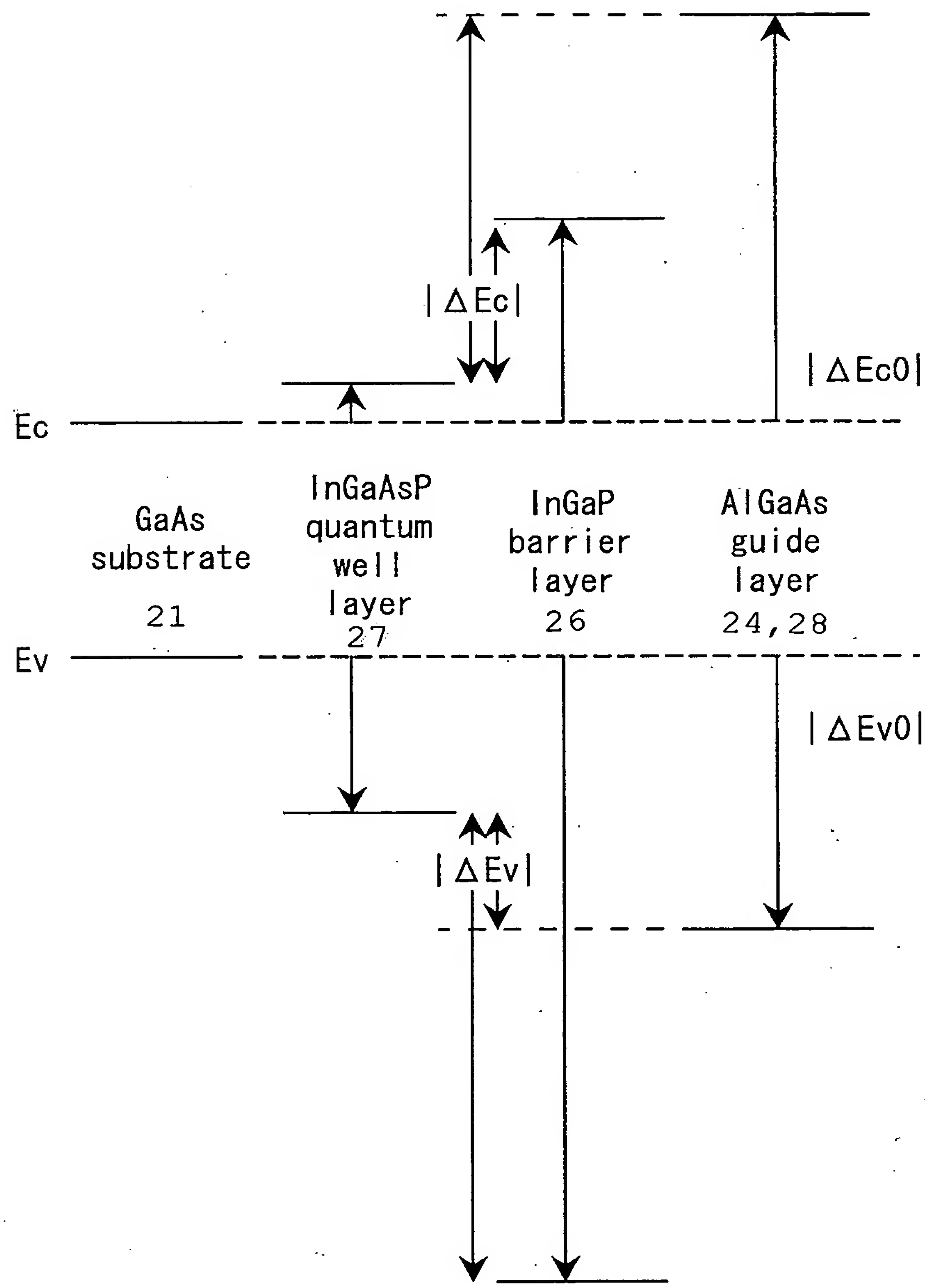
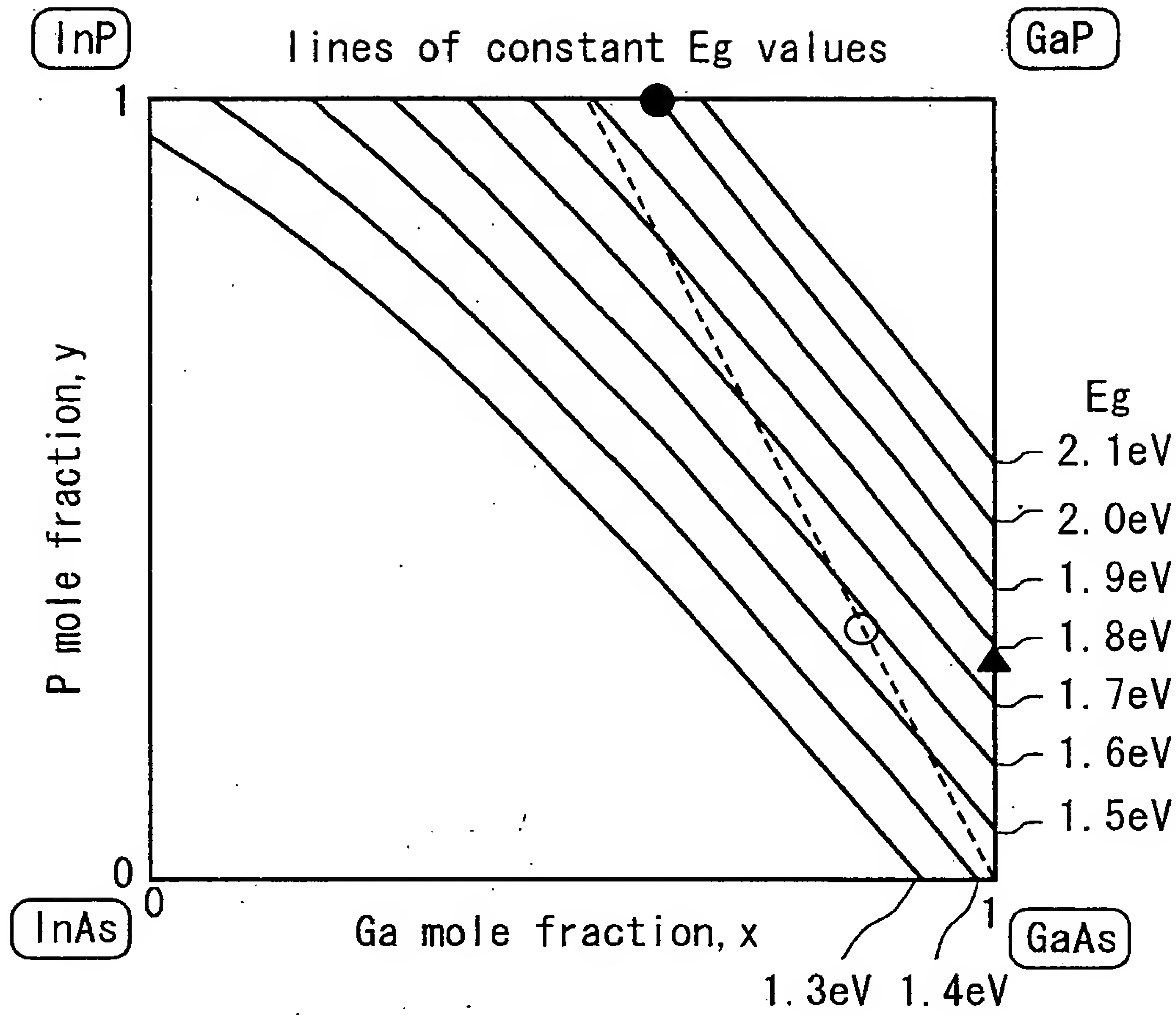


Fig. 3



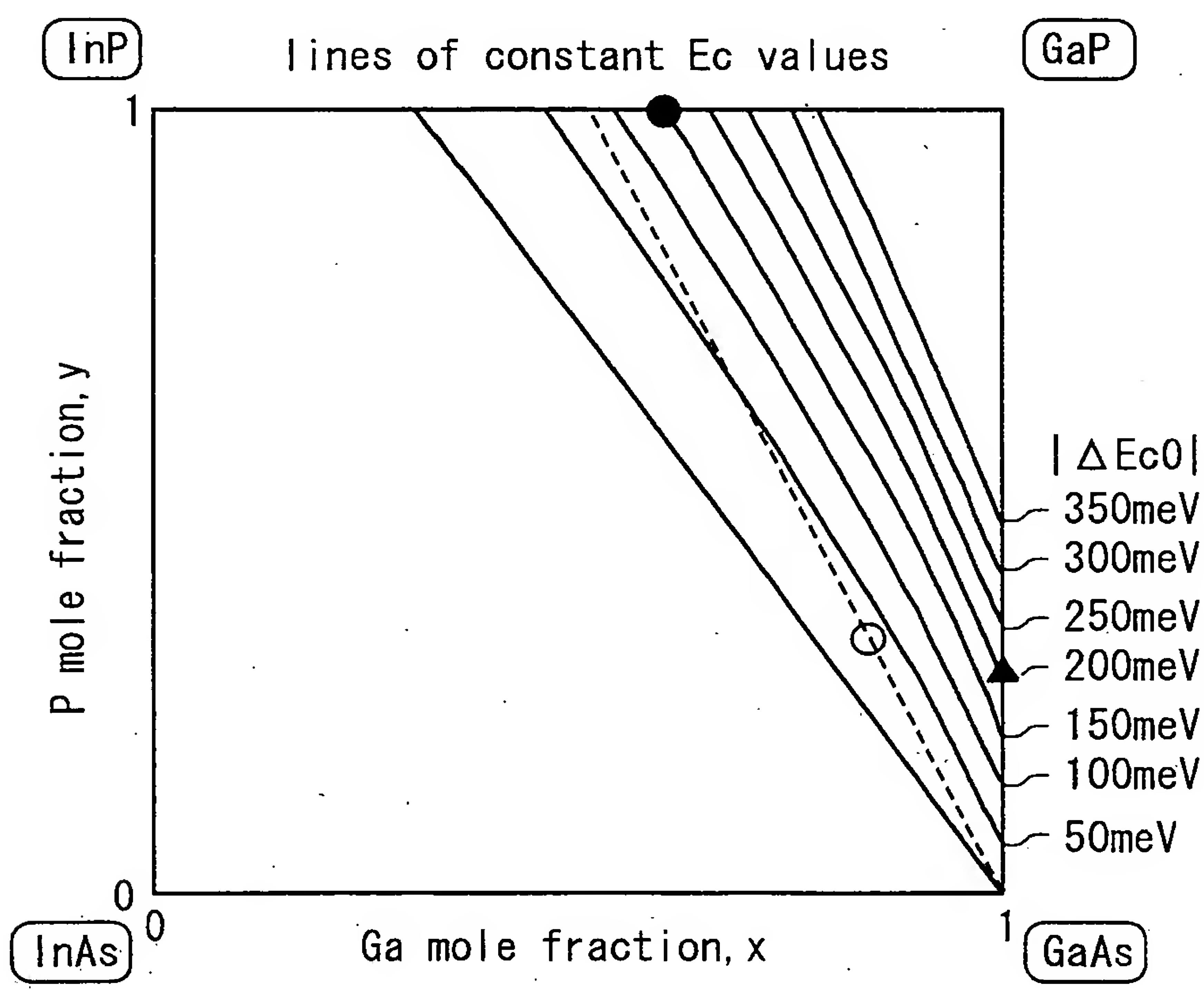
|ΔEc|
|ΔEc0|
Ec
GaAs substrate 21
InGaAsP quantum well layer 27
InGaP barrier layer 26
AlGaAs guide layer 24,28
Ev
|ΔEv0|
|ΔEv|

Fig. 4



InP
lines of constant Eg values
GaP
1
0
P mole fraction, y
Eg
2.1eV
2.0eV
1.9eV
1.8eV
1.7eV
1.6eV
1.5eV
InAs
0
Ga mole fraction, x
1
GaAs
1.3eV
1.4eV

Fig. 5



InP
lines of constant Ec values
GaP
1
0
P mole fraction, y
|ΔEc0|
350meV
300meV
250meV
200meV
150meV
100meV
50meV
InAs
0
Ga mole fraction, x
1
GaAs

Fig. 6

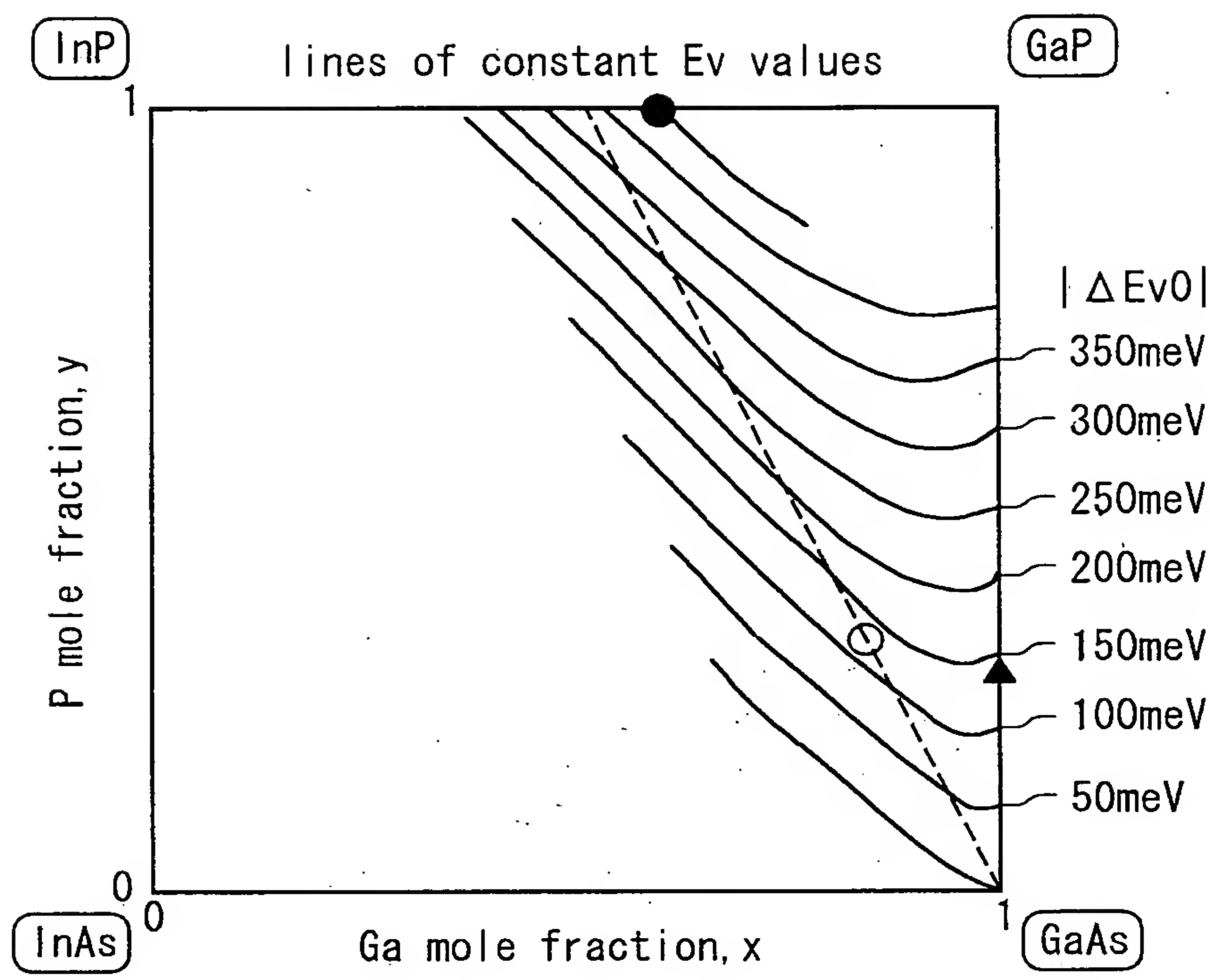

InP
lines of constant Ev values
GaP
1
|ΔEv0|
350meV
300meV
250meV
200meV
150meV
100meV
50meV
P mole fraction, y
0
0
InAs
Ga mole fraction, x
1
GaAs

Fig. 7

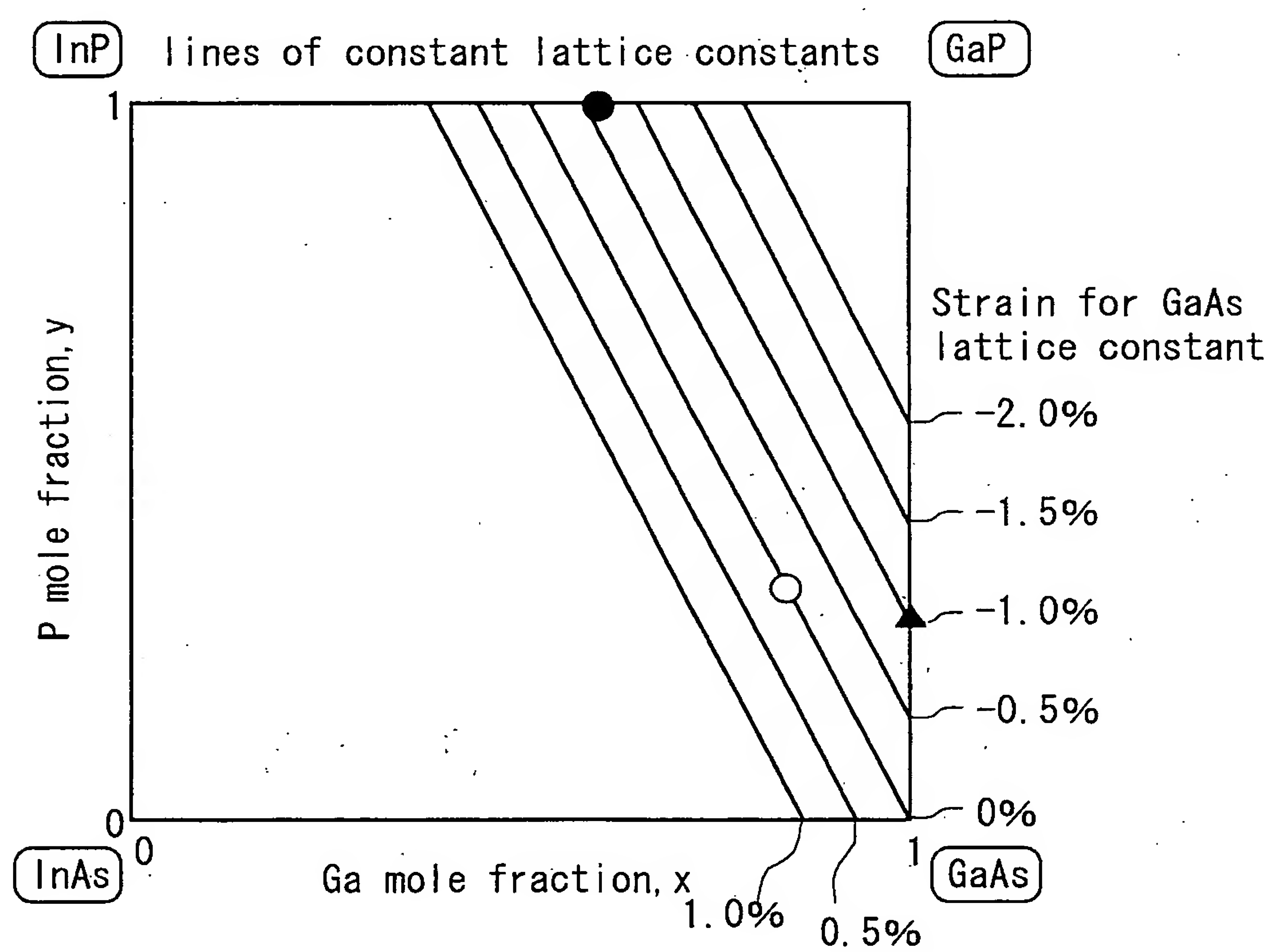
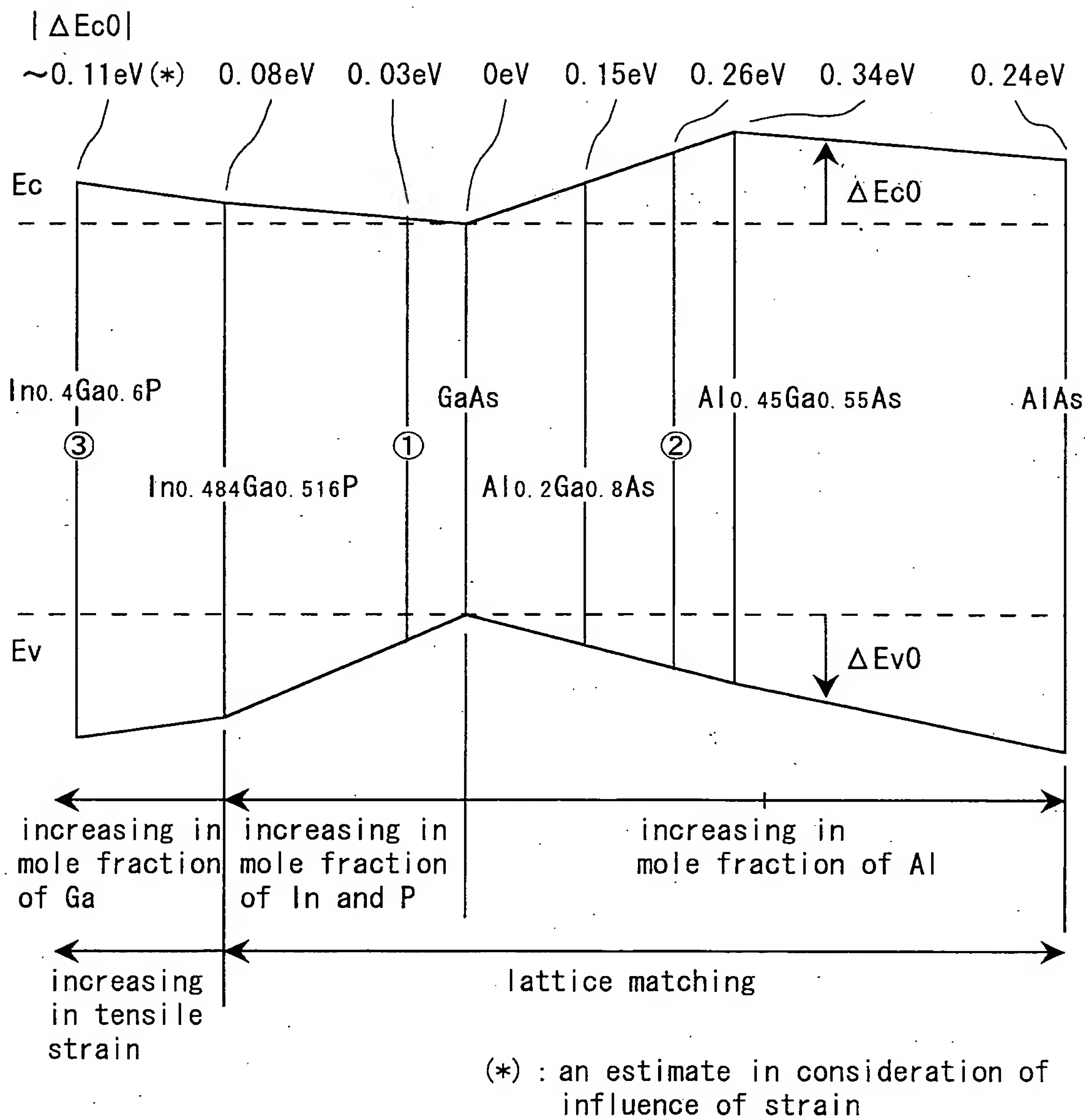

InP
lines of constant lattice constants
GaP
1
Strain for GaAs
lattice constant
-2.0%
-1.5%
-1.0%
-0.5%
0%
P mole fraction, y
0
0
InAs
Ga mole fraction, x
1
GaAs
1.0%
0.5%

Fig. 8



|ΔEc0|
~0.11eV(*)
0.08eV
0.03eV
0eV
0.15eV
0.26eV
0.34eV
0.24eV
Ec
ΔEc0
$In_{0.4}Ga_{0.6}P$
③
$In_{0.484}Ga_{0.516}P$
①
GaAs
$Al_{0.2}Ga_{0.8}As$
②
$Al_{0.45}Ga_{0.55}As$
AlAs
Ev
ΔEv0
increasing in mole fraction of Ga
increasing in mole fraction of In and P
increasing in mole fraction of Al
increasing in tensile strain
lattice matching
(*) : an estimate in consideration of influence of strain

Fig. 9

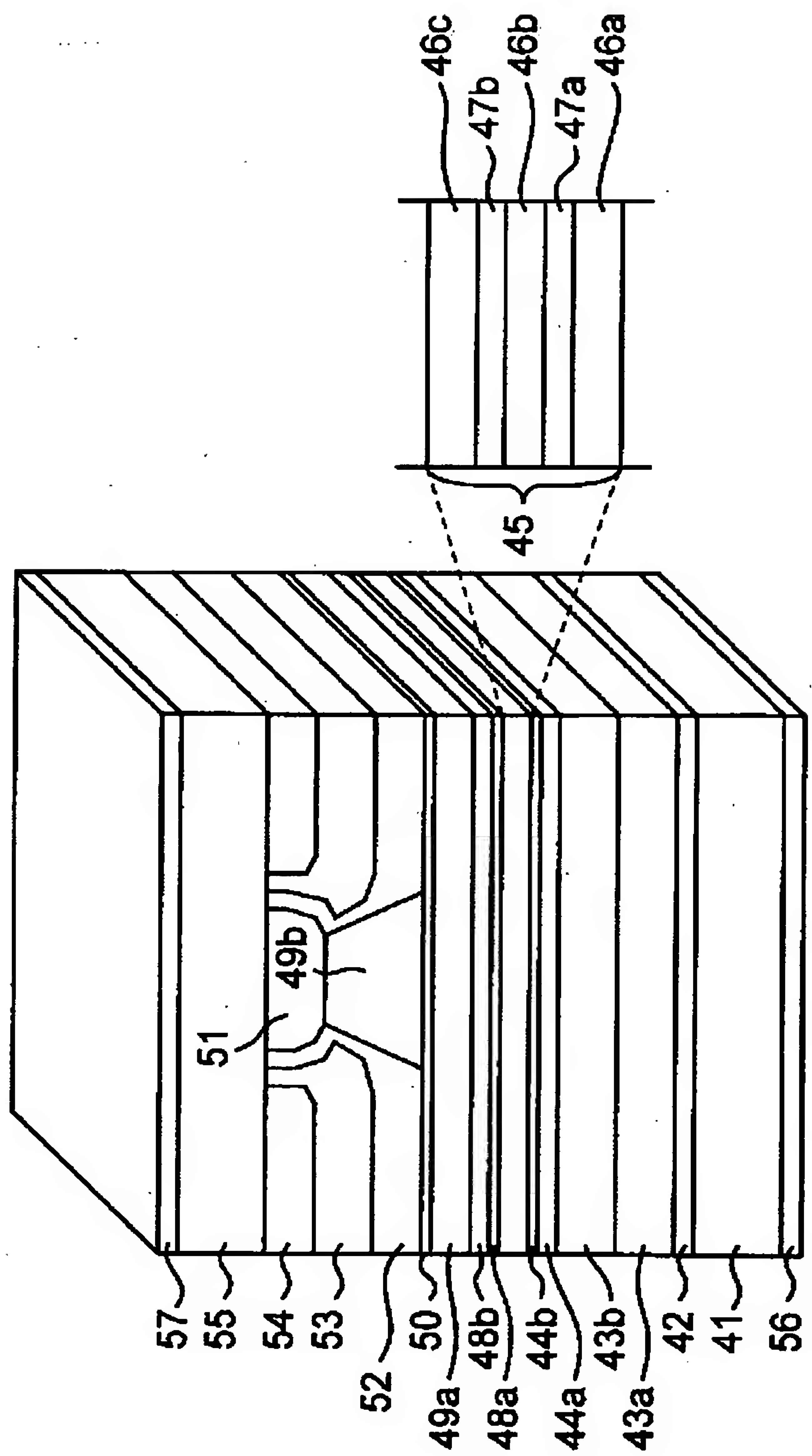

46c
47b
46b
47a
46a
45
51
49b
57
55
54
53
52
50
49a
48b
48a
44b
44a
43b
43a
42
41
56

Fig. 10

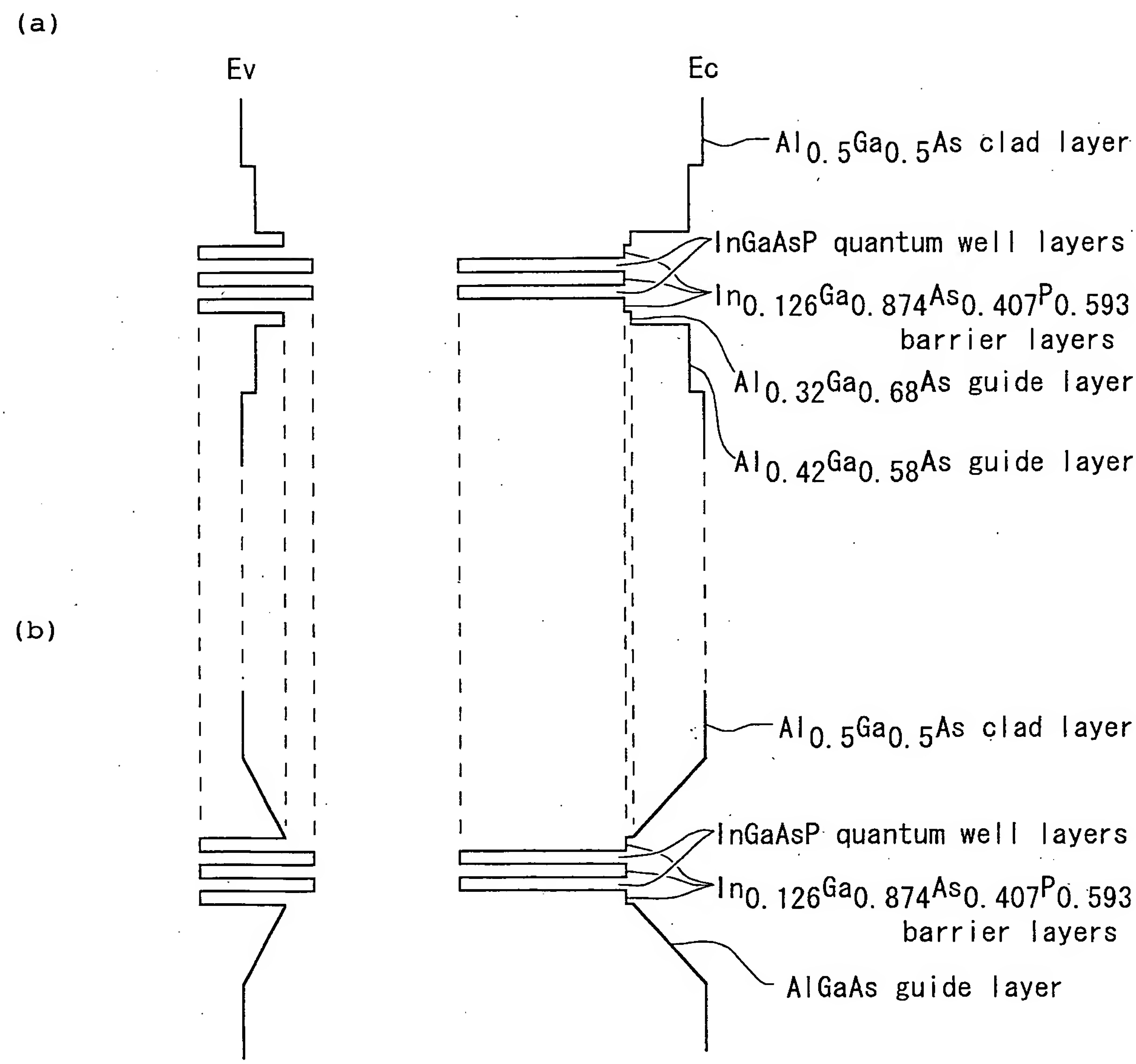

(a)
Ev
Ec
Al0.5Ga0.5As clad layer
InGaAsP quantum well layers
In0.126Ga0.874As0.407P0.593 barrier layers
Al0.32Ga0.68As guide layer
Al0.42Ga0.58As guide layer
(b)
Al0.5Ga0.5As clad layer
InGaAsP quantum well layers
In0.126Ga0.874As0.407P0.593 barrier layers
AlGaAs guide layer

Fig. 11

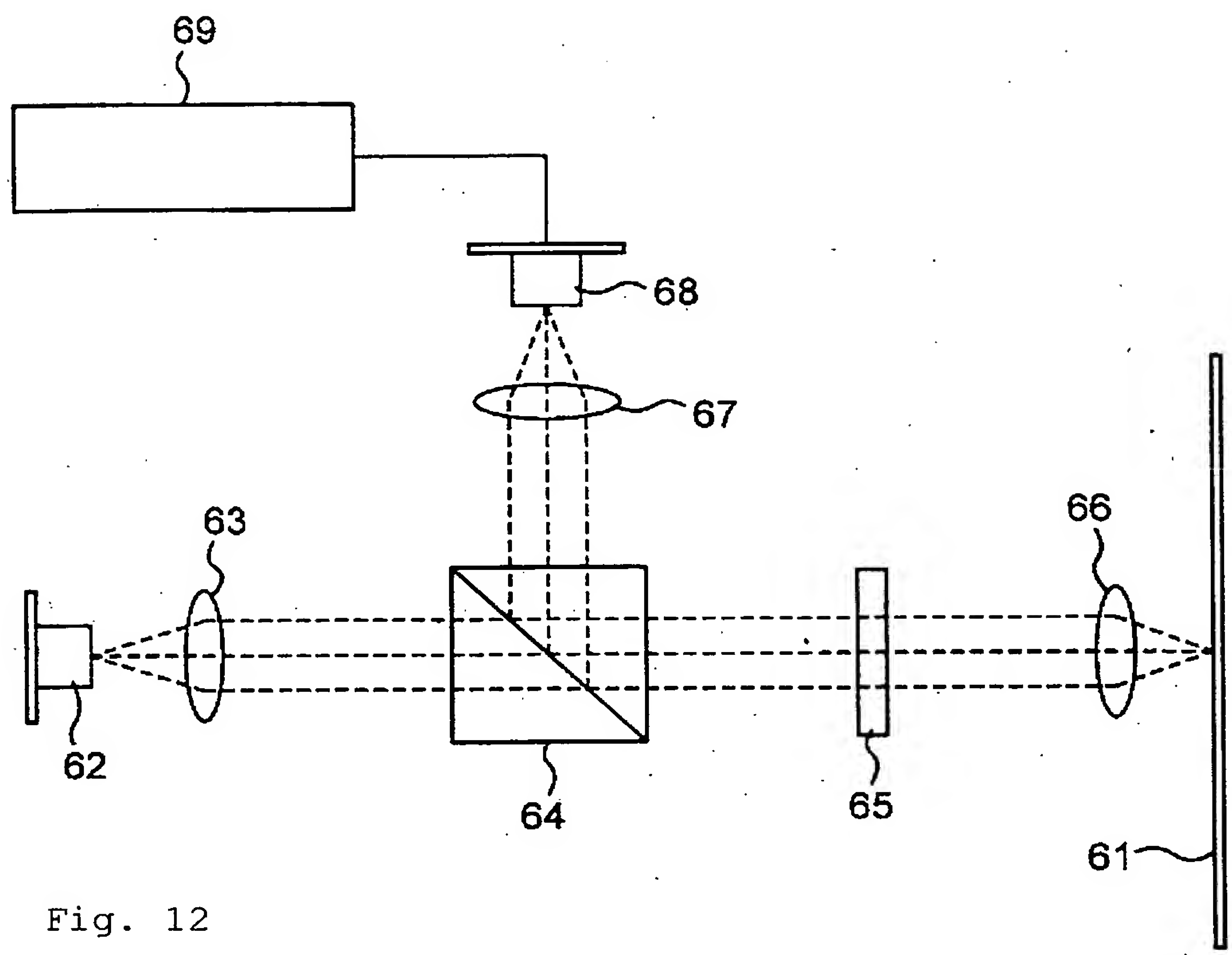


Fig. 12

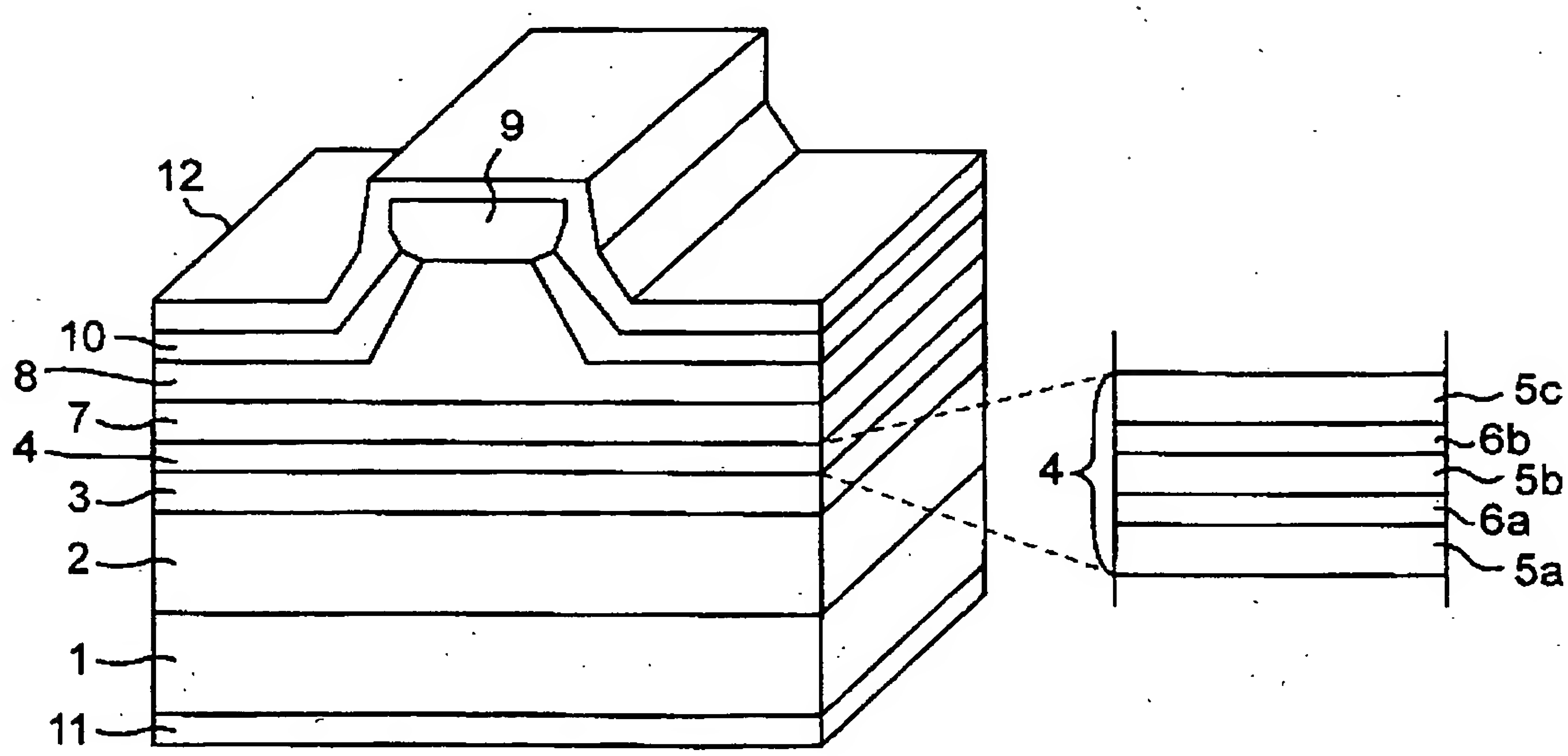
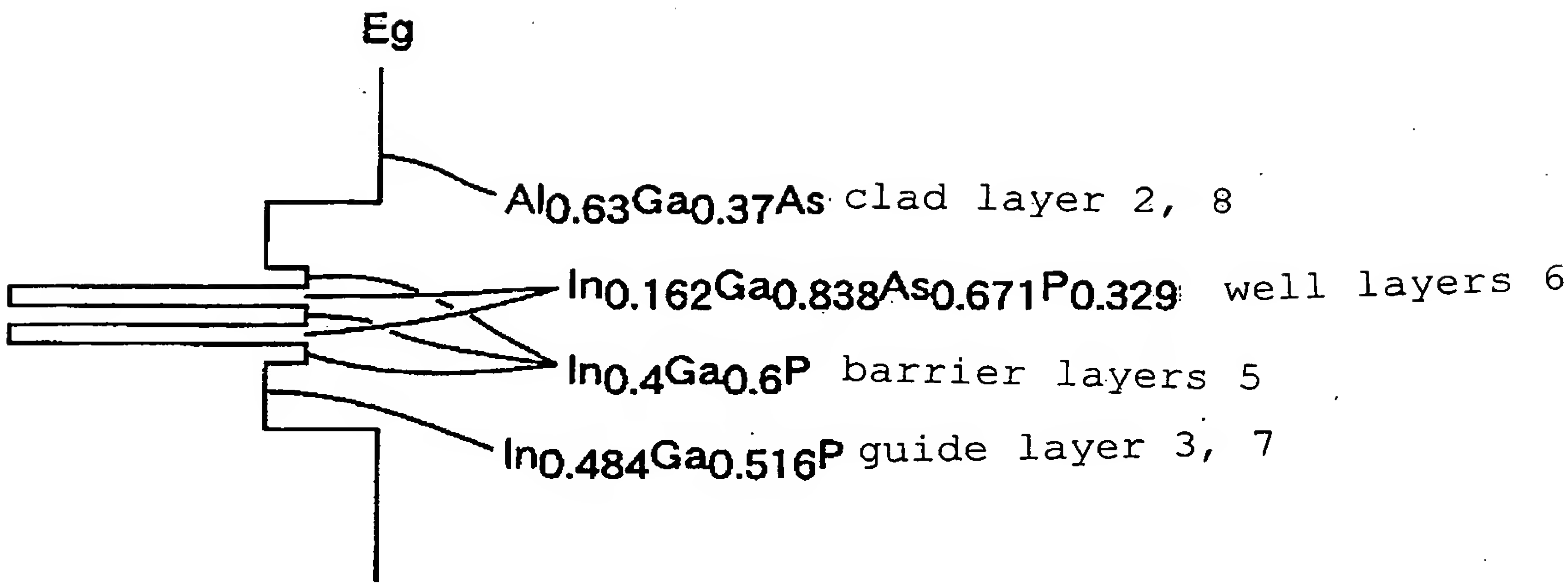


Fig. 13


Eg
$Al_{0.63}Ga_{0.37}As$ clad layer 2, 8
$In_{0.162}Ga_{0.838}As_{0.671}P_{0.329}$ well layers 6
$In_{0.4}Ga_{0.6}P$ barrier layers 5
$In_{0.484}Ga_{0.516}P$ guide layer 3, 7

Document name: Abstract

Summary:

Object: To provide an Al-free semiconductor laser device capable of remarkably improving the characteristics regardless of the level of ΔEg.

Solution: An active region is provided in a DQW structure composed of InGaP barrier layers 26 and InGaAsP well layers 27, the InGaAsP well layers being lattice-matched with a GaAs substrate 21. Guide layers 24, 28 are formed of an AlGaAs having an Al mole fraction larger than 0.20. As a result, ΔEc between the guide layers 24, 28 and the well layers 27 can be set to 0.12 eV or more, so that the overflow of electrons from the well layers 27 can be suppressed. Furthermore, by the combination with the InGaAsP well layers 27, the guide layers 24, 28 of a small Eg could enlarge $|\Delta Ec|$ between the well layers 27 and the guide layers 24, 28 while $|\Delta Ev|$ remains small. That is, barrier formation against the hole injection into the well layers 27 can be prevented and moreover the overflow of electrons from the well layers 27 can be suppressed.

Selected figure: Fig. 3